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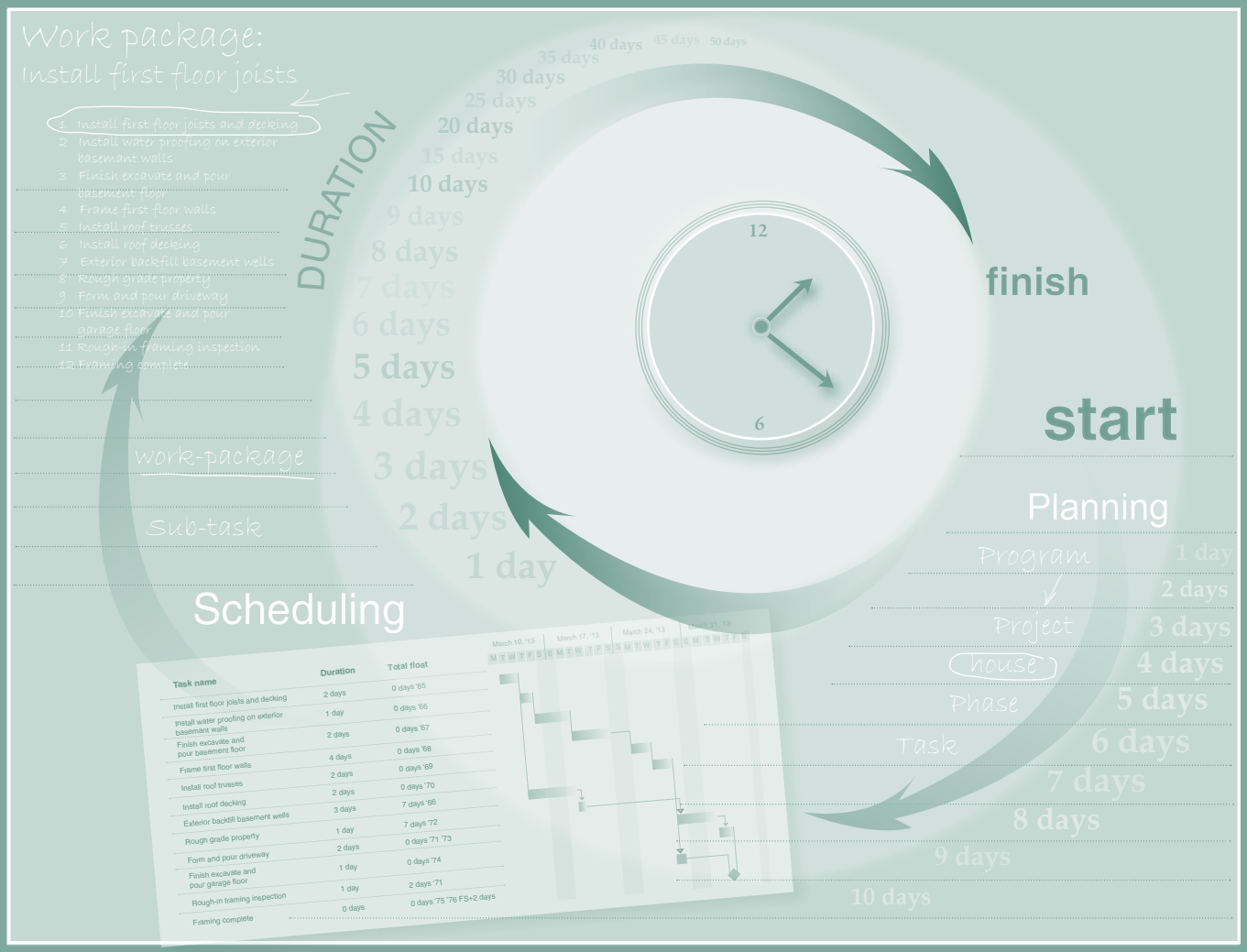

GAO Schedule Assessment Guide

Best Practices for project schedules

"From May 30, 2012 - April 30, 2013, GAO is seeking input and feedback on this Exposure Draft from all interested parties. See page 2 for more information."

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Abbreviations

BEI	baseline execution index
BOE	basis of estimate
CFM	Office of Construction and Facilities Management
CLIN	contract line item number
CPM	critical path method
DEAMS	Defense Enterprise Accounting and Management System
DHS	U.S. Department of Homeland Security
DOE	U.S. Department of Energy
DRRS	Defense Readiness Reporting System
ERP	enterprise resource planning
EVM	earned value management
FAA	Federal Aviation Administration
FNET	finish no earlier than
FNLT	finish no later than
FTE	full-time equivalent
GCSS-Army	Army Global Combat Support System
GFEBS	General Fund Enterprise Business System
G/R	giver/receiver
IMS	integrated master schedule
IPT	Integrated Product Team
LCCE	life-cycle cost estimate
LOE	level of effort
MFO	must finish on
MSO	must start on
PMB	performance measurement baseline
PMO	Program Management Office
SNET	start no earlier than
SNLT	start no later than
SOO	statement of objectives
SOW	statement of work

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TSA	Transportation Security Administration
TPO	Transformation Program Office
USCIS	U.S. Citizenship and Immigration Services
WBS	work breakdown structure

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Preface

The U.S. Government Accountability Office is responsible for, among other things, assisting the Congress in its oversight of the federal government, including agencies' stewardship of public funds. To use public funds effectively, the government must meet the demands of today's changing world by employing effective management practices and processes, including the measurement of government program performance. In addition, legislators, government officials, and the public want to know whether government programs are achieving their goals and what their costs are.

Toward these objectives, In March 2009, we published the GAO *Cost Estimating and Assessment Guide* as a consistent methodology based on best practices that can be used across the federal government to develop, manage, and evaluate capital program cost estimates. The methodology outlined in the *Cost Estimating and Assessment Guide* is a compilation of best practices that federal cost estimating organizations and industry use to develop and maintain reliable cost estimates throughout the life of an acquisition program.

This schedule guide is a companion to the *Cost Guide*. A consistent methodology for developing, managing, and evaluating capital program cost estimates includes the concept of scheduling the necessary work to a timeline, as discussed in the *Cost Guide*. Simply put, schedule variances are usually followed by cost variances. Because some program costs such as labor, supervision, rented equipment, and facilities cost more if the program takes longer, a reliable schedule can contribute to an understanding of the cost impact if the program does not finish on time. In addition, management tends to respond to schedule delays by adding more resources or authorizing overtime. Further, a schedule risk analysis allows for program management to account for the cost effects of schedule slippage when developing the life-cycle cost estimate. A cost estimate cannot be considered credible if it does not account for the cost effects of schedule slippage.

Thus, a well-planned schedule is a fundamental management tool that can help government programs use public funds effectively by specifying when work will be performed in the future and measuring program performance against an approved plan. Moreover, as a model of time, an integrated and reliable schedule can show when major events are expected as well as the completion dates for all activities leading up to them, which can help determine if the program's parameters are realistic and achievable. A program's success depends in part on the quality of its schedule. A well-formulated schedule can help analyze how change

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affects the program. A schedule that contains many concurrent activities, unrealistic activity durations or logic, or a significant number of constrained start or finish dates is a common indicator of poor program performance. Accordingly, a schedule will serve as a warning that a program may need an overtarget budget or schedule.

Developing the scheduling concepts introduced in the *Cost Estimating and Assessment Guide,* the GAO *Schedule Assessment Guide* presents them as ten best practices associated with developing and maintaining a reliable, high-quality schedule. A companion to the *Cost Guide,* the GAO *Schedule Assessment Guide* serves also to present guiding principles for our auditors in evaluating the economy, efficiency, and effectiveness of government programs.

We intend to update the Schedule Assessment Guide to keep it current. Comments and suggestions from experienced users, as well as recommendations from experts in the scheduling, cost estimating, and program acquisition disciplines, are always welcome. Please click on this link https://tell.gao.gov/schedulecommentguide to provide us with comments on the Guide.

If you have any questions concerning this guide, you may contact me at (202) 512-6412 or personst@gao.gov. Contact points for our Office of Congressional Relations and Office of Public Affairs may be found on the last page of this guide. Major contributors to this project are listed on page 200.

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Introduction and Concepts

The success of a program depends in part on having an integrated and reliable master schedule that defines when and how long work will occur and how each activity is related to the others. A schedule is necessary for government acquisition programs for many reasons. The program schedule provides not only a road map for systematic project execution but also the means by which to gauge progress, identify and resolve potential problems, and promote accountability at all levels of the program. A schedule provides a time sequence for the duration of a program's activities and helps everyone understand both the dates for major milestones and the activities that drive the schedule. A program schedule is also a vehicle for developing a time-phased budget baseline. Moreover, it is an essential basis for managing tradeoffs between cost, schedule, and scope. Among other things, scheduling allows program management to decide between possible sequences of activities, determine the flexibility of the schedule according to available resources, predict the consequences of managerial action or inaction on events, and allocate contingency plans to mitigate risk. Following changes in a program, the schedule is used to forecast the effects of delayed, deleted, and added effort, as well as possible avenues for time and cost recovery. In this respect, schedules can be used to verify and validate proposed adjustments to the planned time to complete.

The GAO *Schedule Assessment Guide* is intended to expand on the scheduling concepts introduced in the *Cost Estimating and Assessment Guide* by providing ten best practices to help managers and auditors ensure that the program schedule is reliable. The reliability of the schedule determines the credibility of the program's forecasted dates for decision making.

Ten Best Practices

The ten best practices associated with a high-quality and reliable schedule and their concepts are as follows:

Capturing all activities. The schedule should reflect all activities as defined in the project's work breakdown structure (WBS), which defines in detail the work necessary to accomplish a project's objectives, including activities both the owner and contractors are to perform.

Sequencing all activities. The schedule should be planned so that critical project dates can be met. To do this, activities need to be logically sequenced—that is, listed in the order in which they are to be carried out. In particular, activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until

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other activities are completed (successor activities), should be identified. Date constraints and lags should be minimized and justified. This helps ensure that the interdependence of activities that collectively lead to the completion of events or milestones can be established and used to guide work and measure progress.

Assigning resources to all activities. The schedule should reflect the resources (labor, materials, overhead) needed to do the work, whether they will be available when needed, and any funding or time constraints.

Establishing the duration of all activities. The schedule should realistically reflect how long each activity will take. When the duration of each activity is determined, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be reasonably short and meaningful and allow for discrete progress measurement. Schedules that contain planning and summary planning packages as activities will normally reflect longer durations until broken into work packages or specific activities.

Verifying that the schedule can be traced horizontally and vertically. The detailed schedule should be horizontally traceable, meaning that it should link products and outcomes associated with other sequenced activities. These links are commonly referred to as “hand-offs” and serve to verify that activities are arranged in the right order for achieving aggregated products or outcomes. The integrated master schedule (IMS) should also be vertically traceable—that is, varying levels of activities and supporting subactivities can be traced. Such mapping or alignment of levels enables different groups to work to the same master schedule.

Confirming that the critical path is valid. The schedule should identify the program critical path—the path of longest duration through the sequence of activities. Establishing a valid critical path is necessary for examining the effects of any activity’s slipping along this path. The program critical path determines the program’s earliest completion date and focuses the team’s energy and management’s attention on the activities that will lead to the project’s success.

Ensuring reasonable total float. The schedule should identify reasonable float (or slack)—the amount of time by which a predecessor activity can slip before the delay affects the program’s estimated finish date—so that the schedule’s flexibility can be determined. Large total float on an activity or path indicates that the activity or path can be delayed without jeopardizing the finish date. The length of delay that can be

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accommodated without the finish date's slipping depends on a variety of factors, including the number of date constraints within the schedule and the amount of uncertainty in the duration estimates, but the activity's total float provides a reasonable estimate of this value. As a general rule, activities along the critical path have the least float.

Conducting a schedule risk analysis. A schedule risk analysis uses a good critical path method (CPM) schedule and data about project schedule risks and opportunities as well as statistical simulation to predict the level of confidence in meeting a program's completion date, determine the time contingency needed for a level of confidence, and identify high-priority risks and opportunities. As a result, the baseline schedule should include a buffer or reserve of extra time.

Updating the schedule using actual progress and logic. Progress updates and logic provide a realistic forecast of start and completion dates for program activities. Maintaining the integrity of the schedule logic at regular intervals is necessary to reflect the true status of the program. To ensure that the schedule is properly updated, people responsible for the updating should be trained in critical path method scheduling.

Maintaining a baseline schedule. A baseline schedule is the basis for managing the project scope, the time period for accomplishing it, and the required resources. The baseline schedule is designated the target schedule, subject to a configuration management control process, against which project performance can be measured, monitored, and reported. The schedule should be continually monitored so as to reveal when forecasted completion dates differ from planned dates and whether schedule variances will affect downstream work. A corresponding baseline document explains the overall approach to the project, defines custom fields in the schedule file, details ground rules and assumptions used in developing the schedule, and justifies constraints, lags, long activity durations, and any other unique features of the schedule.

The ten best practices represent the key concepts of a reliable schedule in no particular order; they are not a series of steps for developing the schedule.

The federal audit community is the primary audience for this guide. Agencies that do not have a formal policy for creating or maintaining integrated master schedules will also benefit from the guide because it will inform them of GAO's criteria for assessing a schedule's credibility. Besides GAO, auditing agencies include Inspectors General and audit

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services such as the Naval Audit Service and the Army Audit Agency. Following the text discussion of the best practices, an appendix lists key questions and documentation that members of the federal audit community who assess program schedules will find useful. The remainder of this section introduces the concepts and activities entailed in the integrated master schedule; the critical path method; and planning, scheduling, and the scheduler.

The Integrated Master Schedule

As a document that integrates the planned work, the resources necessary to accomplish that work, and the associated budget, the IMS should be the focal point of program management. In this guide, an IMS constitutes a program schedule that includes the entire required scope of effort, including the effort necessary from all government, contractor, and other key parties for a program's successful execution from start to finish.[1]

An IMS connects all the scheduled work of the government and the contractor in a network, or collection of logically linked sequences of activities. The sequences clearly show how related portions of work depend on one another, including the relationships between the government and contractors. Although the IMS includes all government, contractor, and external effort, the government program management office is ultimately responsible for its development and maintenance. In this respect, the government program management office must ensure that the schedule is as logical and realistic as possible. The IMS must be a complete and dynamic network. That is, the IMS should consist of logically related activities whose forecasted dates are automatically recalculated when activities change. If the schedule is not dynamic, planned activities will not react logically to changes, and the schedule will not be able to identify the consequences of changes or possible managerial action to respond to them.

In general, schedules can refer to programs and projects. In this guide, a "program" encompasses an entire acquisition program from beginning to end, including all government and contractor effort. An IMS may be made up of several or several hundred individual schedules that represent

[1]We recognize that different organizations may use the term "integrated master schedule" differently; for example, an IMS is often used to refer solely to the prime contractor schedule. Our use of "integrated" implies the schedule's incorporation of all activities—those of the contractor and government—necessary to complete a program.

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portions of effort within a program. These individual schedules are "projects" within the larger program. For example, a program IMS may consist of individual project schedules for the prime contractor, the government program management office, and a government testing laboratory.

As discussed in Best Practice 1, the IMS includes summary, intermediate, and all detailed schedules. At the highest level, the summary schedule provides a strategic view of the activities and milestones necessary to start and complete a project. The intermediate schedule includes all information displayed in the summary schedule, as well as key program activities and milestones that show the important steps in achieving high-level milestones. At the lowest level, the detailed schedule lays out the logically sequenced day-to-day effort to reach program milestones. Ideally, one schedule serves as the summary, intermediate, and detailed schedule by simply rolling up lower levels of effort into summary activities or higher-level work breakdown structure (WBS) elements.

The program or project team should develop the schedules and, in doing so, include the program manager, schedulers, and subject matter experts or managers responsible for specific areas of work. Managers responsible for resources should approve the areas of a schedule they are committed to support. If the schedule is not planned in sufficient detail or collaboratively by team members and stakeholders, then opportunities for process improvement (for example, identifying redundant activities), what-if analysis, and risk mitigation will be missed. Moreover, activity owners responsible for managing the day-to-day effort and the most experienced team members who perform the work are the best source of resource estimates. Activity owners must be able to explain the logic behind their resource estimates; if resources are without justification, the schedule will falsely convey accuracy.

The Critical Path Method

The critical path method is used to derive the critical activities—that is, activities that cannot be delayed without delaying the end date of the program. The amount of time an activity can slip before the program's end date is affected is known as "total float."

Critical activities have the least amount of float and, therefore, any delay in them generally causes the same amount of delay in the program's end date. Activities with little total float are called "near-critical" activities, because they can quickly become critical if their small amount of total

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float is used up in a delay. Management must closely monitor critical and near-critical activities by using sound schedule practices.

Unless the IMS represents the entire scope of effort and the effort is correctly sequenced through network logic, the scheduling software will report an incorrect or invalid critical path. That is, the critical path will not represent the activities affecting the program finish date. With no accurate critical path, management cannot focus on the activities that will be detrimental to the project's key milestones and finish date if they slip.

Planning, Scheduling, and the Scheduler

Project planning is a process within program management. An integral stage of management, it results primarily in an overall program execution strategy. The overall strategy is documented in the project plan, which defines, among other things,

- project scope;
- project objectives and requirements;
- stakeholders;
- organizational and work breakdown structures;
- design, procurement, and implementation; and
- risk and opportunity management plans.

Project planning is the basis for controlling and managing project performance, including managing the relationship between cost and time.

Scheduling is a distinct process that follows the planning process. The schedule is essentially a model of the project plan. It calculates the dates on which activities are to be carried out according to the project plan. As a model of time, the schedule incorporates key variables such as nonworking calendar periods, contingency, resource constraints, and preferred sequences of work activities to determine the duration and the start and finish dates of activities and key deliverables.

Planning and scheduling are continual processes throughout the life of a project. Planning may be done in stages throughout the project as stakeholders learn more details. This approach to planning, known as rolling wave planning, is discussed in Best Practice 3. Scheduling involves the management and control of the schedule over the project's life cycle. However, in no case should planning be concurrent with scheduling. In other words, work and strategies for executing the work must be planned first before activities can be scheduled.

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By creating and maintaining the schedule, a scheduler interprets and documents the project plan developed by those responsible for managing and for executing the work. The scheduler is responsible for creating, editing, reviewing, and updating the schedule and ensuring that project and control account managers follow a formal schedule maintenance process. Interpreting the project's sequence of work entails responsibility for alerting program management to threats to the critical path, the degradation of float, and the derivation and use of schedule contingency (these concepts are discussed in Best Practices 6, 7, and 8). The scheduler must also modify the schedule in accordance with approved change requests, including rolling wave planning details, changes in scope, and changes in resource constraints. Maintaining a reliable schedule allows the scheduler to identify the effects of delayed activities or unplanned events on the planned sequence of activities, as well as possible mitigation strategies to prevent significant delays in planned work. The scheduler must track and report actual work performance against the plan, including the production of variances, forecasts, and what-if analyses.

The remainder of this text consists of detailed definitions and descriptions of the ten best practices.

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Best Practice 1: Capturing All Activities

Best Practice 1: The schedule should reflect all activities as defined in the project's work breakdown structure (WBS), which defines in detail the work necessary to accomplish a project's objectives, including activities both the owner and contractors are to perform.

A schedule represents an agreement for executing a program. It should reflect all activities (steps, events, required work, and outcomes) to accomplish the deliverables described in the program's WBS. An IMS should be based on critical path method scheduling that contains all the work represented in logically linked activities representing the execution plan. At its summary level, the IMS gives a strategic view of summary activities and milestones necessary to start and complete a project. At its most detailed, the schedule clearly reflects the WBS and defines the activities necessary to produce and deliver each product. The amount of detail should be sufficient to identify the longest path of activities through the entire program.

Capturing All Effort

The IMS should reflect all effort necessary to successfully complete the program, regardless of who performs it. Failing to include all work for all deliverables, regardless of whether they are the government's responsibility or the contractor's, can hamper project members' understanding the plan completely and the project's progressing toward a successful conclusion. If activities are missing from the schedule, then other best practices will not be met. Unless all necessary activities are accounted for, no one can be certain whether all activities are scheduled in the correct order, resources are properly allocated, missing activities will appear on the critical path, or a schedule risk analysis will account for all risk. Because the schedule is used for coordination, the absence of necessary elements will hinder coordination, increasing the likelihood of disruption and delay. A comprehensive IMS should reflect all a program's activities and recognize that uncertainties and unknown factors in schedule estimates can stem from, among other things, data limitations. A schedule incorporates levels of detail that depend on the information available at any point in time through a process known as rolling wave planning. Rolling wave planning is described in Best Practice 3.

A program IMS is not simply the prime contractor's schedule; it is a comprehensive plan of all government, contractor, subcontractor, and key vendor work that must be performed. Along with complete contract life cycle effort, the schedule must account for related government effort such as design reviews, milestone decisions, government-furnished equipment, and testing. It is also important to include the government effort that leads to final acceptance of the product or service—for example, certain activities that only the government can perform, such as reviewing and accepting deliveries, obtaining permits, and performing program reviews. Schedulers should be aware of how long these government activities take because they often have a clear effect on

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schedules; for instance, a program phase cannot begin until the government review is complete. In addition, if risk mitigation plans have been determined and agreed on then mitigation activities—particularly activities with scope and assigned resources—should also be captured in the schedule.[2]

It is the responsibility of the government program management office to integrate all government and contractor work into one comprehensive program plan that can be used to reliably forecast key program dates. Moreover, all who are affected should clearly agree on what final actions constitute the completion of the project. For instance, if the scope includes financial closeout, contract disputes, and final payment activities, these should be completed before the finish milestone.

Case Study 1: Attempts in Varying Degrees to Capture All Effort, from *DOD Business Transformation,* GAO-11-53

Four DOD enterprise resource planning system schedules differed in the extent to which they captured all activities, as well as in their integration of government and contractor activities. For example, the Defense Enterprise Accounting and Management System Program Management Office (PMO) did not have a schedule that integrated government and contractor activities. The PMO maintained internal schedules that reflected government-only activities, but these activities were not linked to contractor activities. While the Army's Global Combat Support System schedule identified contractor activities, it contained only key government milestones for the program. Other government activities, such as testing events and milestones beyond December 2010, were not captured in the schedule. Instead, they were displayed in isolated, high-level illustrated documents. The Expeditionary Combat Support System program schedule contained detailed activities associated with government effort and contractor effort. However, the government activities were not fully linked to contractor activities, so that updates to government activities did not directly affect scheduled contractor activities. Finally, while the General Fund Enterprise Business System schedule captured government and contractor activities, dependencies between key milestones in deployment, software

[2]More information on formal risk assessment is available in Best Practice 8, as well as in GAO *Cost Estimating and Assessment Guide*, GAO-09-3SP.

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release, and maintenance were not linked, precluding a comprehensive view of the entire program.

GAO, *DOD Business Transformation: Improved Management Oversight of Business System Modernization Efforts Needed,* GAO-11-53 (Washington, D.C.: October 7, 2010).

Milestone, Detail, and Summary Activities

Planned effort and events are represented in a schedule by a combination of milestones, detail activities, and summary activities. Milestones are points in time that have no duration but that denote the achievement or realization of key events and accomplishments such as program events or contract start dates. Because milestones lack duration, they do not consume resources. Two important milestones that every schedule should include are the project start and the finish. No work should begin before the start milestone, and all project scope must be completed before the finish milestone.

Figure 1: A Milestone's Dates

Activity name	Duration (in days)	Start	Finish
Budget and design complete	0	1-9-13	1-9-13

Source: GAO.

A best practice is to create the schedule from primarily detail activities and to include milestones only to reflect major events or deliverables.[3] A milestone should have clear conditions for completion. Examples of milestones include the start and finish of the design stage, start and finish of subcontractor work, and key hand-off dates between parties. The presence of too many milestones in the schedule may mask the activities necessary to achieve key milestones and may prevent the proper recording of actual progress. That is, when too many milestones are introduced into a schedule, the activity sequences that are most likely to delay milestone achievement become increasingly difficult to identify. If

[3]For example, Federal Aviation Administration (FAA) service organizations employ standard program milestones when planning, executing, and reporting progress on investment programs. The standard program milestones are documented along with a description, completion criteria, WBS reference or crosswalk, and the decision authority.

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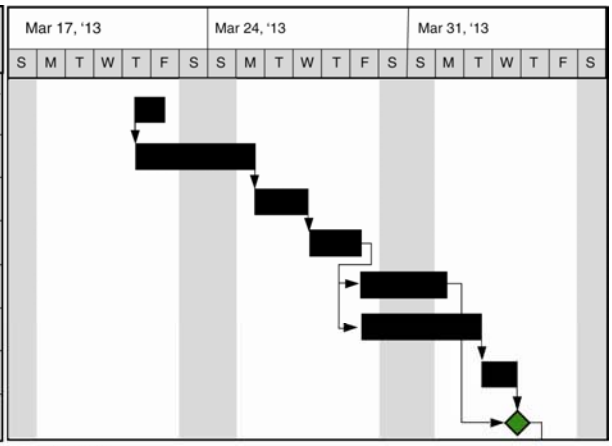
work is represented by milestones, actual progress recorded in the schedule cannot be used to forecast the dates of key events.

Detail activities (also known as “normal” or “work” activities) are at the lowest level of the WBS and represent actual discrete work that is planned to be performed in the project. They are measurable portions of effort. Often they result in a discrete product or component, logically linked to other preceding and succeeding activities in order to form logical sequences and parallel paths of work that must be accomplished to complete the project. Logically related paths of detail activities are linked to milestones to show the progression of work that it is planned to carry out. Detail activities have an estimated duration—that is, a planned estimate of the time it will take to complete the work—and are assigned resources. The status of detail activities is examined periodically to record actual progress. Figure 2 shows an example of a sequence of activities necessary to complete framing in a house construction project.

Figure 2: Detail Activities

Activity name	Duration (in days)	Start	Finish
Rough grade property	1 day	3-19-13	3-20-13
Frame first floor walls	4 days	3-19-13	3-25-13
Install roof trusses	2 days	3-25-13	3-27-13
Install roof decking	2 days	3-27-13	3-29-13
Rough-in framing inspection	1 day	3-29-13	4-1-13
Form and pour driveway	2 days	3-29-13	4-2-13
Finish excavate and pour garage	1 day	4-2-13	4-3-13
Framing complete	0 days	4-3-13	4-3-13



Source: GAO.

Certain scheduling software packages include summary activities as an option. Summary activities are grouping elements that are useful for showing the time that activities of lower levels of detail require. Summary activities derive their start and end dates from lower-level activities. Because the work is done at the level of detailed activities, summary activities should never be linked to or from other activities. Figure 3 shows a summary activity, rolling up the time and effort required during the budget and design phase of a house construction project.

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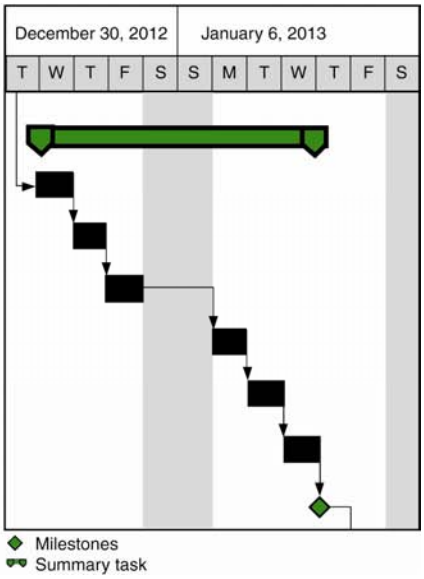
Figure 3: Summary Activities

Activity name	Duration (in days)	Start	Finish
Budget and design	**6**	**1-2-13**	**1-9-13**
Create budget	1	1-2-13	1-2-13
Choose and hire architect	1	1-3-13	1-3-13
Finalize design	1	1-4-13	1-4-13
Apply for mortgage pre-approval	1	1-7-13	1-7-13
Secure construction loan	1	1-8-13	1-8-13
Secure construction insurance	1	1-9-13	1-9-13
Budget and design complete	0	1-9-13	1-9-13



Source: GAO.

Level of Effort Activities

In addition to detailed work activities and milestone events, other activities in schedules represent effort that has no measurable output and cannot be associated with a physical product or defined deliverable. These level of effort (LOE) activities are typically related to management and other oversight that continues until the detailed activities they support have been completed. Progress on LOE activities is based on the passage of time, not the accomplishment of some discrete effort. In schedules, they should be seen as contributing to the comprehensive plan of all work that is to be performed.

LOE is represented by summary activities in certain scheduling software packages, and some schedulers represent LOE effort with detailed activities of estimated long duration. When represented as summary or long-duration detailed activities in a fully networked schedule, LOE activities may inadvertently define the length of a project or program and become critical. LOE activities should never be on the critical path because they do not represent discrete effort. The main way to circumvent issues associated with including LOE in a schedule is to represent the effort as an activity that has been designed specifically for that purpose—that is, one that derives its duration from detailed activities. These types of activities, used specifically to represent LOE, are known

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as “hammock” activities, and they are included in certain scheduling software packages.

Constructing an IMS

The overall size of the IMS depends on many factors, including the complexity of the program and the technical, organizational, and external risk involved. In addition, the intended use of the schedule in part dictates its size. That is, a schedule with many short-duration activities may make the schedule unusable for other purposes such as strategic management or risk analysis. The schedule should not be too detailed to interfere with its use. However, the more complex a program is, the more complex the IMS must be.

Generally speaking, the level of detail in the schedule should reflect the level of information available on the portion of the work that is planned to be accomplished. Both the government and the contractor must define the effort required to complete the program in a way that fully details the entire scope and planned flow of the work. In this manner, the IMS will be defined to the level necessary for executing daily work and periodically controlling the project. Schedules that are defined at too high a level may disguise risk that is inherent in lower-level activities. In contrast, too much detail in a schedule will make it difficult to manage progress and may convolute the calculation of critical paths.

The IMS ideally takes the form of a single schedule file that includes all activities. However, it may also be a set of separate schedules, perhaps representing the work of separate contractors and government offices, networked together through external links. Regardless of how this is achieved, the IMS schedules must be consistent horizontally and vertically. Horizontal and vertical integration form the basis of Best Practice 5.

The IMS includes the summary, intermediate, and all detailed schedules. At the highest level, a summary schedule should provide a strategic view of summary activities and milestones necessary to start and complete a project. Decision makers use summary schedules to view overall progress toward key milestones. Summary schedules are roll-ups of lower-level intermediate and detail schedules. The dates of these milestones are automatically calculated through the established network logic between planned activities.

An intermediate schedule includes all information displayed in the summary schedule, as well as key program activities and milestones that

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show important steps toward high-level milestones. Intermediate schedules may or may not include detailed work activities. For instance, an intermediate schedule may show the interim milestone accomplishments necessary before a major milestone decision or summarized activities related to a specific trade or resource group. A properly defined IMS can facilitate tracking key program milestones such as major program decision points or deliverables. The important program milestones can be summarized along with the specific required activities leading up to the milestone event.

A detailed schedule, the lowest level of schedule, lays out the logically sequenced day-to-day effort to achieve program milestones. While each successively lower level of schedule shows more detailed date, logic, resource, and progress information, summary, intermediate, and detailed schedules should be integrated in a way such that higher-level schedule data respond dynamically and realistically to progress (or lack of progress) at the lower levels. Delays in lower-level schedules should be immediately relayed to intermediate and summary schedules. A summary schedule presented to senior management should not display on-time progress and on-time finish dates if the same milestones in lower-level schedules are delayed.

Ideally, the same schedule serves as the summary, intermediate, and detailed schedule by simply rolling up lower levels of effort into summary activities or higher-level WBS elements. When fully integrated, the IMS shows the effect of delayed or accelerated government activities on contractor activities, as well as the opposite. Not every team member needs to digest all the information in the entire schedule. For example, decision makers need strategic overviews, whereas specialist contractors need to see the detail of their particular responsibility. Both sets of information should be available from the same data in the same schedule.

In some instances, the government program management office and its contractors might use different scheduling software. However, given the same schedule data, different software products will produce different results because of variations in algorithms and functionality. Attempting to manually resolve incompatible schedules in different software can become time-consuming and expensive. If the use of different software cannot be avoided, the parties should define a process to preserve integrity between the different schedule formats and to verify and validate the converted data whenever the schedules are updated.

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The IMS must include planning for all activities that have to be accomplished for the entire duration of the program. A schedule of planned effort for one block, increment, or contract for a multiyear multiphased program is not a plan sufficient to reliably forecast the finish date for the program. Without such a view, a sound basis does not exist for knowing with any degree of confidence when and how the project will be completed. A comprehensive IMS reflects all activities for a program and recognizes that there can be uncertainties and unknown factors in schedule estimates because of limited data, technical difficulty, inadequate resources, or other factors in the organizational environment. Uncertainties regarding future activities are incorporated into an IMS in part by the rolling wave process (discussed in Best Practice 3) and through schedule risk analysis (Best Practice 8). Management should verify that all subcontractor schedules are correctly integrated in the IMS at the level of detail appropriate to their risk level. Case study 2 highlights the lack of accountability associated with the absence of an IMS.

Case Study 2: Establishing an IMS, from *Military Readiness*, GAO-09-518

From its inception in 2002 until November 2008, the Defense Readiness Reporting System (DRRS) Implementation Office did not have an integrated master schedule. It had long been allowed to proceed, therefore, without a basis for executing the program and measuring its progress. In fact, the only identifiable milestone for the program before November 2008 was the date that DRRS was to achieve full operational capability, which was originally estimated for fiscal year 2007. Later, this slipped to fiscal year 2008 and fiscal year 2011 and, at the time of assessment, had become fiscal year 2014—a 7-year delay.

GAO, *Military Readiness: DOD Needs to Strengthen Management and Oversight of the Defense Readiness Reporting System*, GAO-09-518 (Washington, D.C.: September 25, 2009).

Work Breakdown Structure

A work breakdown structure is the cornerstone of every program because it defines in detail the work necessary to accomplish a program's objectives. For example, a typical WBS reflects the requirements to be accomplished to develop a program, and it provides a basis for identifying resources and activities necessary to produce deliverables. A WBS is also a valuable communication tool between systems engineering, program management, and other functional organizations because it provides a clear picture of what has to be accomplished by decomposing

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the project scope into finite deliverables. Accordingly, it is an essential element for identifying activities in a program's IMS.

A well-structured WBS helps promote accountability by identifying work products that are independent of one another. It also provides the framework for developing a schedule plan that can easily track technical accomplishments—in terms of resources spent in relation to the plan as well as completion of activities—allowing quick identification of cost and schedule variances.

A WBS deconstructs a program's end product into successively greater levels of detail until the work is subdivided to a level suitable for management control. By breaking work down into smaller elements, management can more easily plan and schedule the program's activities and assign responsibility for the work. It is also essential for establishing a reliable schedule baseline. Establishing a product-oriented WBS such as the one in figure 4 is a best practice because it allows a program to track cost and schedule by defined deliverables, such as a hardware or software component. This allows program managers to identify more precisely which components are causing cost or schedule overruns and to more effectively mitigate overruns by manipulating their root cause.

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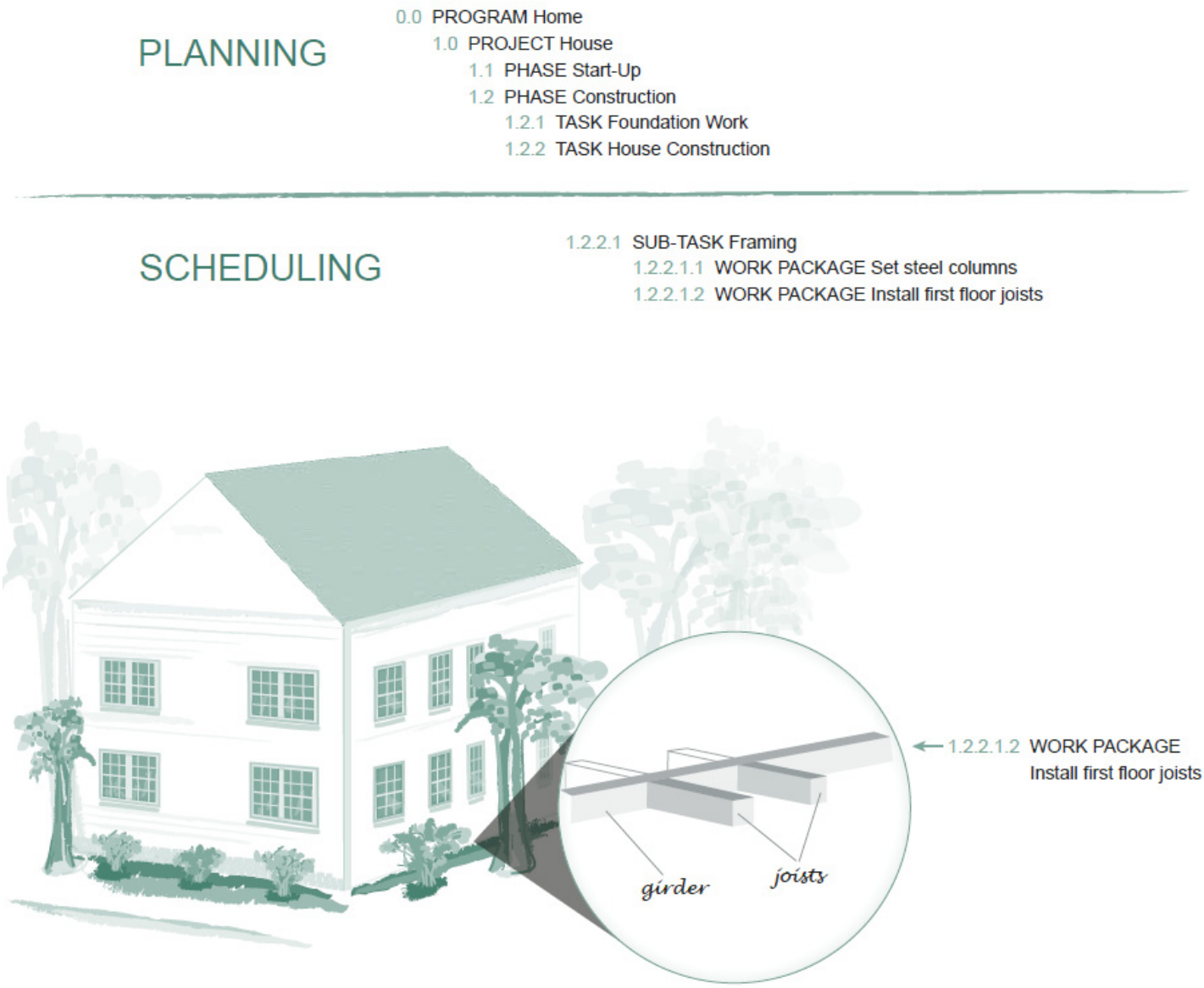
Figure 4: The WBS and Scheduling



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The WBS is the basis of the project schedule and defines what is required as a deliverable. Scheduling activities addresses how the program is going to produce and deliver what the WBS describes. When properly

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planned, the schedule reflects the WBS and therefore defines the activities necessary to produce and deliver the lowest-level deliverable. The schedule is a set of instructions on how the program intends to execute the project. Every activity within the schedule must be traceable to an appropriate WBS element, and every WBS element must have at least one associated activity that is necessary to complete that element clearly identified within the schedule. Aligning the schedule to the program WBS will ensure that the total scope of work is accounted for within the schedule.

In the schedule, the WBS elements are linked to one another through the activities' logical relationships and lead to the end product or final delivery. The WBS progressively deconstructs the deliverables of the entire effort through lower-level WBS elements and control accounts.

The hierarchical nature of the WBS ensures that the entire statement of work accounts for the detailed technical activities and, when completed, facilitates communication between the customer and supplier on cost, schedule, resource requirements, technical information, and the progress of the work.

It is important that the WBS is comprehensive enough to represent the entire program to a level of detail sufficient to manage the size, complexity, and risk associated with the program. There should be only one WBS for each program, and it should match the WBS used for the cost estimate and schedule so that actual costs can be fed back into the estimate with a correlation between the cost estimate and schedule. A well-developed WBS is essential to the success of all acquisition programs.[4]

In addition, the WBS must have an associated WBS dictionary that clearly defines the scope of each individual WBS element and, therefore, the scope of related schedule activities. Activities that are not assigned to WBS elements or are assigned to undefined WBS elements reflect unassigned or undefined project scope. In this manner, the WBS dictionary helps clarify the boundaries between different WBS elements.

[4]See the GAO *Cost Estimating and Assessment Guide* (GAO-09-3SP) for numerous examples of standard work breakdown structures for, among others, surface, sea, and air transportation systems; military systems; communications systems; and systems for construction and utilities.

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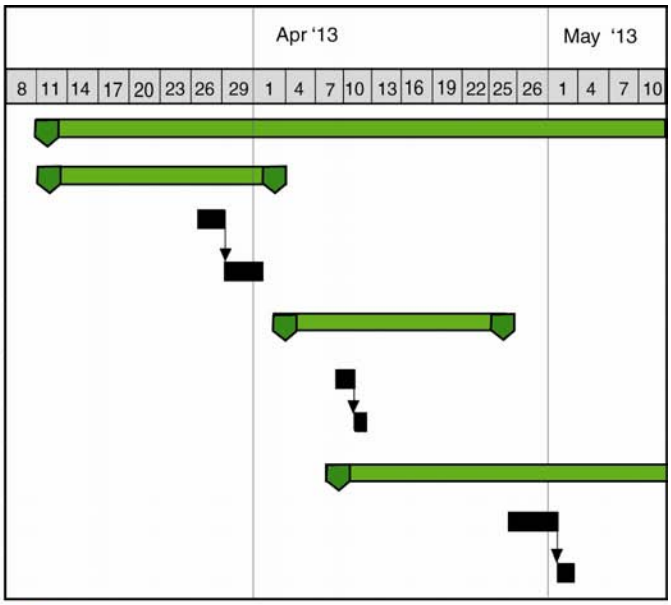
Activity Names

A consistent convention for naming work activities should be established early in a program and carried through its completion. Names for all activities, including summary, milestone, and detailed activities, should be unique and as descriptive as necessary to facilitate communication between all team members. Descriptive activity names will ensure that decision makers, managers, control account managers, task workers, and auditors know what scope of work is required for each activity.

Because activities are instructions for someone to carry out, activity names should be phrased in the present tense with verb-noun combinations, such as “review basis of estimate,” “test level 4 equipment,” or “install and test workstations, room 714.” Milestone descriptive names should be related to an event or a deliverable, such as “Milestone B decision” or “level 4 test results report delivered.” In all cases, descriptive names should be unambiguous and should identify their associated product without the need to review high-level summary activity or preceding activity names. In the example in figure 5, it is not clear which products the detailed inspection activities are associated with without including their respective summary activities and preceding activities in the filtered view.

Figure 5: Redundant Activity Names

Activity name	Start
House construction	3-11-13
Framing	3-11-13
Install roof decking	3-27-13
Inspection	3-29-13
Interior rough-in	4-3-13
Dry-in roof	4-9-13
Inspection	4-11-13
Interior finishes	4-9-13
Install drywall on walls and ceilings	4-25-13
Inspection	5-1-13



Source: GAO.

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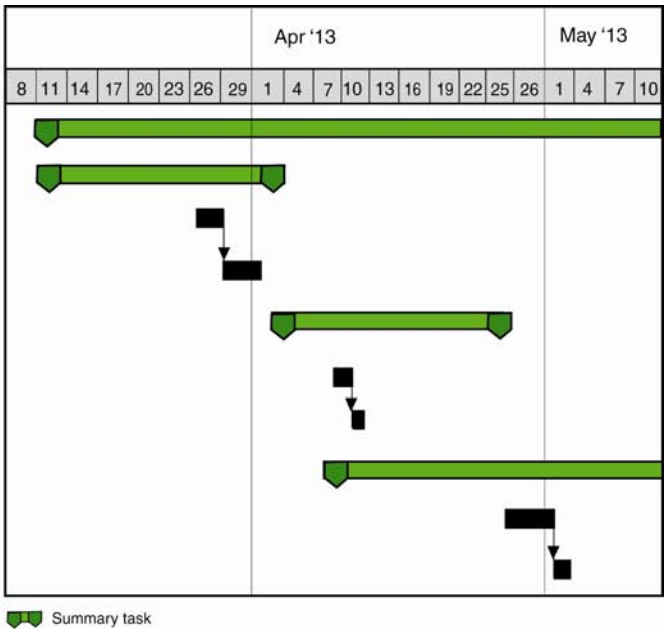
Repetitive naming of activities that are not associated with specific products or phases makes communication difficult between teams, particularly between team members responsible for updating and integrating multiple schedules. However, in figure 6, activity names include their respective products, which are also identified for clarity in their summary activity.

Figure 6: Unique Activity Names

Activity name	Start
House construction	3-11-13
Framing	3-11-13
Install roof decking	3-27-13
Rough-in framing inspection	3-29-13
Interior rough-in	4-3-13
Dry-in roof	4-9-13
Roofing inspection	4-11-13
Interior finishes	4-9-13
Install drywall on walls and ceilings	4-25-13
Drywall screw inspection	5-1-13



Source: GAO.

Individual activities in figure 6 are easier to identify, especially when filters and other analyses are performed on the schedule data and the activities are taken out of the summary-indented activity context. For example, filtering the schedule data to display only critical path activities will not be helpful if activity names are redundant or incompletely identify the work being executed. Communicating to management that “inspection” is a critical path activity is not very useful unless management knows which inspection is meant. Communicating that “drywall screw inspection” is a critical path activity conveys much more usable information and obviates the need to note its summary or predecessor activity. Unique activity names are essential if a schedule is to produce reliable information at the summary, intermediate, and detailed levels.

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Finally, abbreviations specific to programs and agencies should be minimal and, if used, should be defined in either the WBS dictionary or the schedule baseline document.[5]

Activity Codes

In addition to having descriptive names, activities within the schedule must be consistent with key documents and other information through activity or task codes. Activities should be consistent with such information as the related statement of work (SOW) or statement of objectives (SOO) paragraph, WBS element, contractor, location, phase, contract line item number (CLIN), work package number, and control account, as applicable. Every contractor's detailed activities should be associated with an SOW or SOO paragraph at some agreed-on level of detail.[6] Consistent coding can help ensure the vertical integration of the summary and detailed work schedules. Activity names should not directly contain code information. That is, information such as CLIN, SOW, or SOO paragraph numbers should be stored in custom fields rather than appended to activity names.

Each activity should be associated with a unique alpha-numeric code that allows it to be immediately identified, particularly in a complex schedule with many embedded subprojects. Ideally, this unique code preserves the hierarchical relationship between the activity and its parent elements. For example, the activity "Software Unit 1A test" could be mapped to the code "ADZT125" to represent the Alpha project (A), development phase (D), Zeta prime contractor (Z), testing activity (T), and activity ID number (125). Other commonly used codes that are mapped to schedule activities, either placed in separate columns or embedded in a unique identifier, identify the responsible owner of the activity and the related integrated product team (IPT). Codes such as phase, department, area, system, and step also greatly facilitate the filtering and organization of schedule data for reporting, metric analysis, and auditing purposes. LOE activities should be identified as such in the schedule, and government and contractor efforts should be clearly delineated. Any custom text fields

[5]A schedule baseline document and its recommended content are detailed in Best Practice 10.

[6]In addition, a Department of Defense (DOD) program IMS should be vertically traceable to events, accomplishments, and criteria within the integrated master plan (IMP). The IMS includes the detailed activities necessary to support the criteria.

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or coding scheme within the schedule should be defined in the schedule baseline document. Case study 3 shows how activities in a detailed schedule can be quickly sorted, filtered, or categorized using codes.

Case Study 3: Successfully Coding Detailed Work, from *VA Construction,* GAO-10-189

The Department of Veterans Affairs (VA) required by contract that the schedule for the expansion of the medical centers in Cleveland, Ohio, include approximately 2,500 activities in order to sufficiently detail the level of work required. The actual schedule contained 2,725 activities—approximately 75 detail activities per milestone. Each activity was mapped to an activity identification number, building area, and work trade, which allowed the scheduler to quickly filter the schedule by type of work or subcontractor. Additionally, the VA Office of Construction and Facilities Management reviewed the schedule for completeness to ensure that all necessary activities and milestones were included.

GAO, VA Construction: *VA Is Working to Improve Initial Project Cost Estimates, but Should Analyze Cost and Schedule Risks,* GAO-10-189 (Washington, D.C.: December 14, 2009).

Best Practices Checklist: Capturing All Activities

- The WBS is the basis of the project schedule. Its elements are linked to one another with logical relationships and lead to the end product or final delivery. The schedule clearly reflects the WBS and defines the activities necessary to produce and deliver each product.
- The schedule reflects all effort (steps, events, work required, and outcomes) to accomplish the deliverables described in the program's work breakdown structure.
- The IMS includes planning for all activities that have to be accomplished for the entire duration of the program, including all blocks, increments, phases, and so on.
- The IMS includes the summary and intermediate and all detailed schedules. The same schedule serves as the summary, intermediate, and detailed schedule by simply rolling up lower levels of effort into summary activities or higher-level WBS elements.
- The detailed schedule includes all activities the government, its contractors, and others must perform to complete the work, including government-furnished equipment or information, deliverables, or services from other projects.
- The schedule contains primarily detail activities and includes milestones only to reflect major events or deliverables.

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- If the government program management office and its contractor use different scheduling software packages, a process is defined to preserve integrity between the different schedule formats, and the converted data are verified and validated when the schedules are updated.
- Effort that has no measurable output and cannot be associated with a physical product or defined deliverable is represented by level of effort (LOE) activities.
- Activity names are descriptive and clear enough to identify their associated product without the need to review high-level summary or predecessor activity names.
- Activities within the schedule are easily traced to key documents and other information through activity or task codes.

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Best Practice 2: Sequencing All Activities

Best Practice 2: The schedule should be planned so that critical project dates can be met. To do this, activities need to be logically sequenced—that is, listed in the order in which they are to be carried out. In particular, activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until other activities are completed (successor activities), should be identified. Date constraints and lags should be minimized and justified to help ensure that the interdependence of activities that collectively lead to the completion of events or milestones can be established and used to guide work and measure progress.

Once established, a schedule network can forecast reliably—in light of the best information available at that point in time—the start and finish dates of future activities and key events based on the status of completed and in-progress activities. Dates are forecast with some realism by planning work effort in sequences of activities that logically relate portions of effort to one another. The schedule network is a model of all ongoing and future effort related to the program; it establishes not only the order of activities that must be accomplished but also the earliest and latest dates on which those activities can be started and finished to complete the project on time. By establishing the network logic, the schedule can also predict the effect on the project's planned finish date of, among other things, misallocated resources, delayed activities, external events, scope changes, and unrealistic deadlines.

The ability of a schedule to forecast the start and finish dates of activities and key events reliably is directly related to the complexity and completeness of the schedule network. The reliability of the schedule is in turn related to the management's ability to use the schedule to direct the assignment of resources and perform the correct sequence of activities. Activities are related through different types of sequential and parallel predecessor and successor logic.

The more complex a program is, the more complex the schedule must be. However, it is essential that the schedule be as straightforward as possible so that management has a clear indication of the path forward and the necessary resources needed to accomplish activities on time. Convoluted logic techniques such as date constraints, lags, and misused logic links should be eliminated and, if used, employed judiciously and justified in the schedule documentation.

Once all dependencies are in place, the schedule should be presented for the review and approval of management and the persons responsible for performing the work. Major handoffs between groups should be discussed and agreed on to ensure that the schedule correctly models what is expected to happen. This will help everyone see the big picture needed to complete the entire project scope.

Predecessor and Successor Logic

Activities that are logically related within a schedule network are referred to as predecessors and successors. A predecessor activity must start or finish before its successor. The purpose of a logical relationship, or dependency, is to depict the sequence in which activities occur. Such relationships state when activities are planned to start and finish in

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relation to the start and finish of other activities. A logic relationship therefore models the effect of an on-time, delayed, or accelerated activity on subsequent activities. Relationships between activities can be internal—that is, within a particular schedule—or external—that is, between schedules.

Logical relationships between activities indentify whether they are to be accomplished in sequence or in parallel. A sequence of activities is a serial path along which one activity is completed after another. Activities can also be accomplished in parallel or concurrently. A logic relationship linking a predecessor and successor activity can take one of three forms: finish-to-start, start-to-start, and finish-to-finish.[7]

A finish-to-start (F–S) relationship is the most straightforward logical link between a predecessor and successor. In it, a successor activity cannot start until the predecessor activity finishes, creating a simple sequence of planned effort. This logical relationship is the default in most scheduling programs. In figure 7, the installation of roof decking cannot begin until the installation of roof trusses finishes. Note that the installation of the roof decking does not necessarily need to start once the installation of the roof trusses finishes, but it cannot start until the trusses are installed. The “install roof decking” activity may have other predecessors that push its start date further into the future.

[7]A theoretical, fourth combination of logical links exists between predecessor and successor. The start-to-finish (S–F) link has the bizarre effect of directing a successor activity not to finish until its predecessor activity starts, in effect reversing the expected flow of sequence logic. Its use is widely discouraged because it is counterintuitive and it overcomplicates schedule network logic. Examples of activity sequences used to justify the existence of an S–F relationship can usually be rewritten in simple F–S logic by either subdividing activities or finding more appropriate F–S predecessors within the network.

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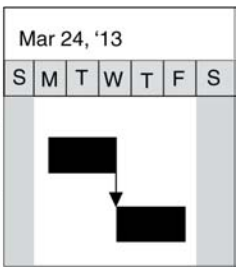
Figure 7: Finish-to-Start Relationship

Activity name	Start	Finish
Install roof trusses	3-25-13	3-27-13
Install roof decking	3-27-13	3-29-13

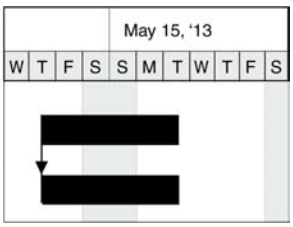


Source: GAO.

A start-to-start (S–S) relationship dictates that a successor activity cannot start until the predecessor activity starts. In the example in figure 8, the application of wall finishes cannot start until the application of drywall texture starts. The S–S relationship does not dictate that wall finishing must start at the same time that drywall texturing starts, but it does indicate that it cannot start until drywall texturing starts. The "apply wall finishes" activity may have other predecessors that push its start date further into the future.

Figure 8: A Start-to-Start Relationship

Activity name	Start	Finish
Apply drywall texture	5-12-13	5-17-13
Apply wall finishes (stain and paint)	5-12-13	5-17-13



Source: GAO.

A finish-to-finish (F–F) relationship dictates that a successor activity cannot finish until the predecessor activity finishes. In figure 9, final landscaping cannot finish until forming and pouring the patio has finished. Again, the F–F relationship does not dictate that landscaping must finish at the same time as pouring the patio finishes, but it cannot finish until the pouring of the patio finishes. The final landscaping activity may have other predecessors that determine its finish date, or it may finish later than the patio pouring activity.

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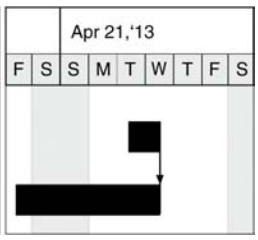
Figure 9: A Finish-to-Finish Relationship

Activity name	Start	Finish
Form and pour patio	4-23-13	4-24-13
Plant trees and shrubs and install final landscaping	4-19-13	4-24-13



Source: GAO.

The majority of relationships within a detailed schedule should be finish-to-start. Finish-to-start relationships are intuitive because most work is accomplished serially. Moreover, F–S relationships are easy to trace within a schedule network and clearly indicate to management which activities must finish before others begin and which activities may not begin until others have been completed. F–S relationships are most easily implemented where work is broken down to small elements.

Start-to-start and finish-to-finish relationships, in contrast, imply parallel or concurrent work. S–S and F–F relationships represent a valid technique for modeling the overlapping of activities. As such, they may be more predominant in schedules that have not yet evolved to a detailed level. However, an overabundance of these relationships in detail schedules may suggest an overly optimistic or unrealistic schedule or shortcuts that have been taken in modeling activities and logic. Particularly in a detailed schedule, their overuse may impair the usefulness of the schedule by, for example, complicating the identification of the critical path. S–S and F–F relationships are also prone to producing unintentional “dangling” relationship logic, an error that is described later in this best practice.

Once the logic has been established to create a network, the scheduling software will calculate a set of start and finish times for each activity, given the relationship logic and the estimated duration of each activity. Ideally, there should be only one date input into the scheduling software—the project start date—and all other dates are calculated by the network logic. Network logic calculates activity dates that define both when an activity may start and finish and when an activity must start and finish in order to meet a specified program completion date. These are known as early and late dates, respectively.

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Each activity has an early start and an early finish date.

- Early start defines the earliest time when an activity may start.
- Early finish defines the earliest time when an activity may finish.

The early start and early finish dates for each activity are calculated by the "forward pass" method. The forward pass determines the early start and early finish times for each activity by adding durations successively through the network, starting at day one. The forward pass will derive the total time required for the entire project by calculating the longest continuous path through the network—that is, the sequence of activities that determines the length of the project, typically known as the critical path. Managing the critical path is the foundation of Best Practice 6.

Each activity also has a late start and a late finish date.

- Late start defines the latest time when an activity must start in order for the project to be completed on time.
- Late finish defines the latest time when an activity must finish in order for the project to be completed on time.

The late start and late finish for each activity are calculated by the "backward pass" method—the opposite of the forward pass. Whereas the forward pass determines early finishes by adding durations to early starts, the backward pass determines late starts by subtracting durations from late finishes.

The difference between an activity's early and late dates is known as total float or slack. Total float is an essential output of critical path method scheduling, and its proper management is the foundation of Best Practice 7.

In figure 10, the excavation and installation of the underground sewer lines may begin as early as February 19 (early start) and finish as early as February 20 (early finish). However, in order for the house construction project to be completed on time, the excavation and installation must begin by February 21; if they do, the project will finish on February 22. The activity therefore has 2 days of total float: the difference between its early start date of February 19 and its late start date of February 21.[8] The

[8]Unless otherwise stated in this guide, "start" and "finish" refer to an activity's early start and early finish dates.

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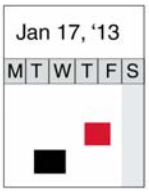
red box in figure 10 represents the late start and late finish dates, and the black box represents the early start and early finish dates.

Figure 10: Early and Late Dates

Activity name	Early start	Late start	Early finish	Late finish
Excavate and install for underground sewer	2-19-13	2-21-13	2-20-13	2-22-13



Source: GAO.

Appendix II gives a detailed example of how to calculate early and late dates using the forward and backward passes.

Incomplete and Dangling Logic

Because a logic relationship dictates the effect of an on-time, delayed, or accelerated activity on subsequent activities, any missing or incorrect logic relationship is potentially damaging to the entire network. Complete network logic between all activities is essential if the schedule is to correctly forecast the start and end dates of activities within the plan.

As a general rule, every activity within the schedule should have at least one predecessor and at least one successor. The two natural exceptions to this rule are the project start milestone, which will have no predecessor, and the project finish milestone, which will have no successor. In some cases, other activities within the schedule may not have predecessor or successor links. For example, a milestone may represent handing off some interim product to an external partner by the program office and therefore has no successor relationship within the schedule. However, any activity that is missing predecessor or successor logic must be clearly justified in the schedule documentation.

Even if an activity has predecessor and successor logic relationships, incorrect or incomplete logic can arise. Networks should be assessed for circular logic—that is, logic that forces two activities to be dependent on each other. Circular logic creates an endless loop of work: an activity cannot have its successor also be its predecessor. In addition, the network should be clear of redundant logic. Redundant logic represents unnecessary logic links between activities. For example, if a sequence of activities A, B, and C exists with a series of finish-to-start logic, there is no need for an additional F–S logic link between A and C.

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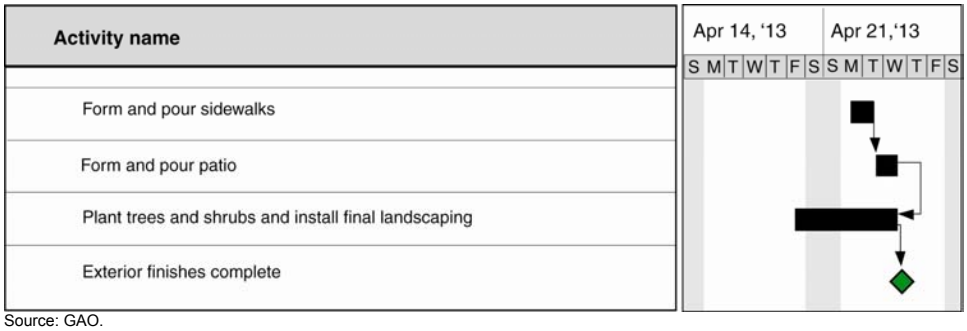
Activities with S–S or F–F relationships should be checked for two types of "dangling" logic. Dangling or "hanging" logic is scheduling logic that is not properly tied to an activity's start or end date. Each activity's start date—other than the start and finish milestones—must be driven by a predecessor activity, and each activity's finish date must drive a successor activity's start or finish. Dangling logic, a form of incomplete logic, can interfere with the valid forecasting of scheduled activities.

The first type of dangling logic occurs when an activity has a predecessor and a successor but its start date is not properly tied to logic. In other words, no preceding activity within the schedule is determining the start date of the activity, with either its start (S–S) or finish (F–S). Figure 11 shows a sequence of activities—form and pour sidewalks, form and pour patio, install final landscaping—and a completion milestone.

Figure 11: Start-Date Dangling Logic



Source: GAO.

"Form and pour patio" has an F–S relationship to its predecessor activity, "form and pour sidewalks," and an F–F relationship with its successor, "plant trees and shrubs and install final landscaping." "Plant trees and shrubs and install final landscaping" in turn has an F–S relationship with the "exterior finishes complete" milestone. Notice that the finish date of "plant trees and shrubs and install final landscaping" is determined by the predecessor relationship to the finish of "form and pour sidewalks"; that is, final landscaping cannot finish until the patio is formed and poured. The problem here is that the start date of "final landscaping" is not determined by any relationship; it is simply determined by the estimated time it will take to accomplish final landscaping and its finish date. Moreover, if "form and pour patio" finishes but "final landscaping" runs longer than planned, the only resolution—according to the original plan—is for "final landscaping" to start earlier. This is a logical solution but practically impossible, because it may have already started before it is determined

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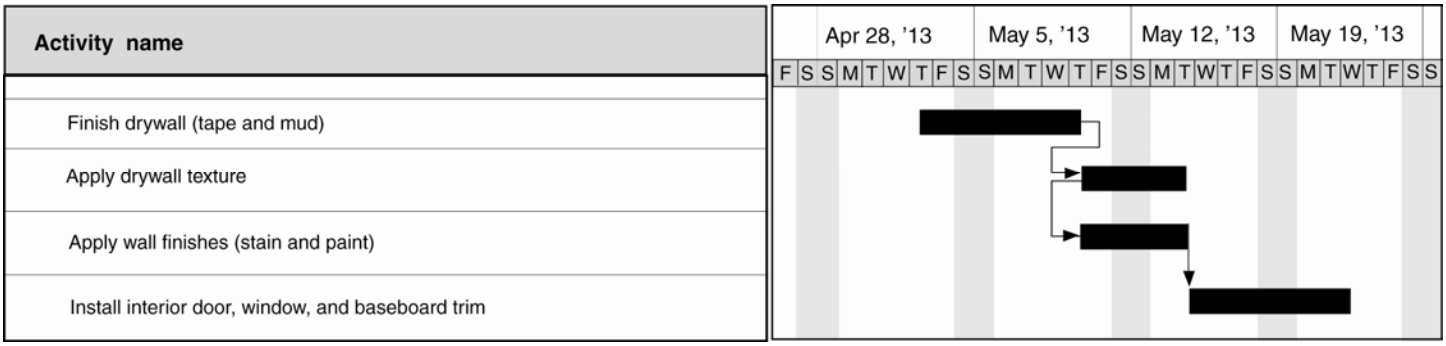
that it takes longer than planned. To correct the dangling logical error, “final landscaping” must have at least one F–S or S–S predecessor link alongside the F–F predecessor relationship to determine its start date. This requirement might make the scheduler find a different predecessor or break “form and pour patio” into two activities.

The second type of dangling logic is similar to the first but involves an activity’s finish date. Figure 12 shows a sequence of activities: finish drywall, apply drywall texture, apply wall finishes, and install trim. “Apply drywall texture” has an F–S predecessor link to “finish drywall” and an S–S successor relationship to “apply wall finishes.”

Figure 12: Finish-Date Dangling Logic



Source: GAO.

In this example, “apply drywall texture” starts once “finish drywall” completes. Once “apply drywall texture” starts, “apply wall finishes” can start. Note, however, that while “apply drywall texture” has a successor, its finish date is not related to any subsequent activity. In other words, “apply drywall texture” can continue indefinitely with no adverse affect on subsequent activities, until it affects the owner’s occupation date—to which it is implicitly linked by an F–S relationship by the scheduling software. To correct the dangling logical error, “apply drywall texture” must have at least one F–S or F–F successor link alongside the S–S successor relationship in order for its finish date to affect downstream activities.

Finally, note that dangling logic is far more dangerous for detail activities than milestones. Milestones have the same start and finish dates, so from a practical standpoint, delaying or accelerating a milestone within the schedule would still affect successor activities, even with start or finish date dangling logic. In point of fact, there is little reason to sequence

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milestones with any logic other than F–S, because milestones simply indicate a point in time. Regardless, all dangling logic should be corrected to ensure that the logic in the schedule is as straightforward and intuitive as possible.

To summarize dangling logic checks:

- Any activity with an F–F predecessor link must also have at least one F–S or S–S predecessor link. If nothing is driving the start date of the activity, then why not start the activity earlier?
- Any activity with an S–S successor link must also have at least one F–S or F–F successor link. If the finish date of the activity is not driving the start of another activity, then why finish the activity?

Complete schedule logic that addresses the logical relationships between predecessor and successor activities is important. The analyst needs to be confident that the schedule will automatically calculate the correct dates when the activity durations change.

Summary Logic

Summary activities should not have logic relationships because their start and finish dates are derived from lower-level activities. Therefore, there is no need for logic relationships on a summary activity in a properly networked schedule.

Summary logic hinders vertical traceability. For example, if the start or finish dates of summary activities are not derived by the planned or actual dates of lower-level activities, then the dates of summary activities may be misrepresented in higher-level versions of the schedule.[9] In addition, tracing logic through summary links does not impart to management the sequence in which lower-level activities should be carried out. Figure 13 gives an example of a linked summary activity. The summary activity “interior rough-in” defines the start date of “HVAC interior rough-in,” “plumbing interior rough-in,” and “install exterior vapor barriers,” rather than the activities’ start dates defining the summary start date. Moreover, because the summary logic masks actual work effort relationships, it may not be clear to management that “HVAC interior rough-in,” “plumbing interior rough-in,” and “install exterior vapor barriers” all depend on “framing complete” occurring.

[9]Vertical traceability is discussed in detail in Best Practice 5.

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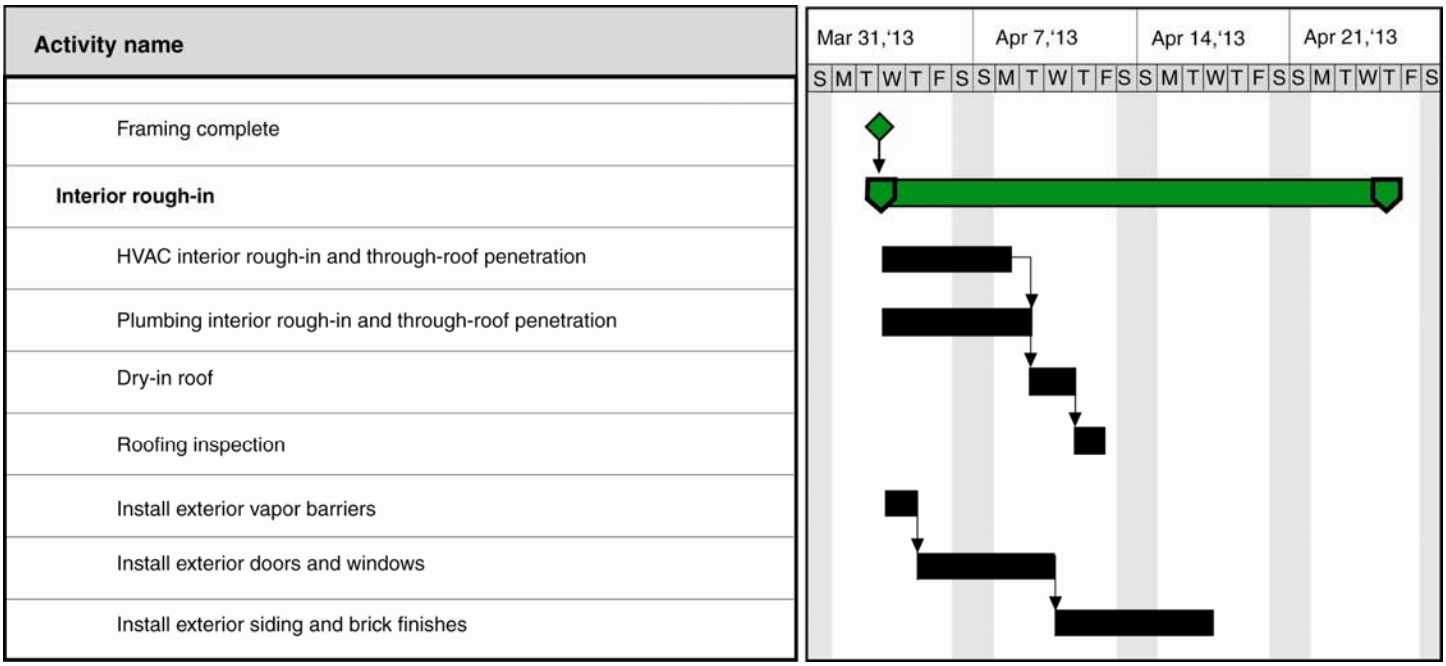
Figure 13: A Linked Summary Activity



Source: GAO.

Case study 4 provides an example of how using summary links may initially make scheduling activities easier but eventually convolutes the network logic.

> Case Study 4: Summary Logic, from *DOD Business Transformation,* GAO-11-53
>
> GAO's analysis of the General Fund Enterprise Business System schedule found that 50 summary activities (12 percent of remaining summary activities) had predecessor links. Program Management Office schedulers used these summary links rather than linking predecessors to their numerous lower-level activities. Because many of the lower-level activities began on the same date, this made updating the schedule simpler: an updated start date for the summary activity forced that same date on all the unlinked lower-level activities.
>
> Despite updating's being made easier, the technique is not considered a best practice. First, summary activities do not represent work and are used simply as grouping elements. They should take

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their start and finish dates from lower-level activities; they should not dictate the start or finish of lower-level activities. Second, linking summary activities obfuscates the logic of the schedule. That is, tracing logic through summary links does not impart to management the sequence in which lower-level activities should be carried out.

GAO, *DOD Business Transformation: Improved Management Oversight of Business System Modernization Efforts Needed,* GAO-11-53 (Washington, D.C.: October 7, 2010).

Date Constraints

Ideally, relationship logic, the duration of activities, and resource availability determine the planned early and late start dates of all activities within the schedule network. However, in some cases it may be necessary to override the calculated start or finish dates of activities by imposing calendar restrictions on when an activity can begin or end. Such restrictions are referred to as date constraints. Constraints can be placed on an activity's start or finish date and can limit the movement of an activity into the past or future or both. Because constraints override network logic and restrict how planned dates respond to actual accomplished effort or resource availability, they should be used only when necessary and only if they are justified in the schedule documentation. Generally, constraints are used to demonstrate an external event's effect on the schedule. For example, constraints may be used to show the expected availability of a production line.

"Not earlier than" constraints affect the forward pass of the schedule and thus may delay a project by pushing some activities' start dates later than permitted by their predecessors. These types of constraints are also known as "past-limiting" in that they prevent activities from starting or finishing earlier than planned but allow them to slip into the future if predecessor activities are delayed.

- Start no earlier than (SNET): schedules an activity to start on or after a certain date even if its predecessors start or finish earlier. That is, it prevents an activity from beginning before a certain date. SNET constraints are also called start on or after constraints.
- Finish no earlier than (FNET): schedules an activity to finish on or after a certain date. That is, it prevents an activity from finishing before a certain date. FNET constraints are also called finish on or after constraints.

"Not later than" constraints affect the backward pass of the schedule and thus may unrealistically accelerate the project. These types of constraints are also known as "future-limiting" in that they prevent activities from

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starting or finishing later than planned but allow them to be accomplished earlier if possible.

- Start no later than (SNLT): schedules an activity to start on or before a certain date. That is, it prevents the activity from starting any later than a certain date. SNLT constraints are also called start on or before constraints.
- Finish no later than (FNLT): schedules an activity to finish on or before a certain date. That is, it prevents an activity from finishing after a certain date. FNLT constraints are also called finish on or before constraints.

"Must" or "mandatory" constraints affect both the forward pass and the backward pass of the schedule, forcing activities to occur on dates regardless of network logic. These types of constraints prevent activities from starting or finishing on any day other than the date assigned.

- Must start on (MSO): schedules an activity to start on a certain date. That is, it prevents the activity from starting any earlier or later than a certain date, thereby overwriting network logic. MSO constraints are also called mandatory start constraints.
- Must finish on (MFO): schedules an activity to finish on a certain date. That is, it prevents the activity from finishing any earlier or later than a certain date, thereby overwriting network logic. MFO constraints are also called mandatory finish constraints.

Date constraints are often categorized as either soft (also referred to as moderate or one-sided) or hard (also referred to as inflexible), depending on how the constraint restricts the ability of the activity to accelerate or slip according to the established network logic.[10] Soft constraints include SNET and FNET constraints. These are called soft because while they restrict the ability of the activity to start or finish early, depending on network logic, they allow the activity to start or finish later than planned. In this respect, these constraints allow delays to permeate the schedule and, given available float, possibly affect the project's end date.

[10]Our definitions of hard and soft constraints assume that a schedule is formulated under forward scheduling. That is, the project start date is firm and all activities are scheduled to occur as soon as possible to determine the project finish date. Under backward scheduling, the project end date is considered firm and all activities are scheduled as late as possible to determine the project start date. Whether the plan is forward or backward scheduled affects how restrictive certain constraints are. For example, under backward scheduling, a finish no earlier than constraint is considered a "hard" constraint.

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Hard constraints include the SNLT, FNLT, MSO, and MFO constraints. SNLT and FNLT constraints prevent activities from starting or finishing later than planned, essentially restricting the ability of any predecessor delays to affect their start and finish dates. While these types of constraints allow activities to start and finish earlier than planned, the acceleration of activities is not usually as big a concern to program management as the delay of activities.

Mandatory start and finish constraints are the most rigid because they do not allow the activity to either take advantage of time savings by predecessor activities or slip in response to delayed predecessors or longer-than-scheduled durations. By setting the early and late dates of an activity equal to each other, a mandatory start or finish constraint immediately eliminates all float associated with the activity and renders them static in time; successors might start on the next day, even though unconstrained logic would not permit it.

Using Date Constraints

As noted previously, date constraints are generally used to demonstrate an external event's effect on the schedule. However, because they prevent activities from responding dynamically to network logic, including actual progress and availability of resources, they can affect float calculations and the identification or continuity of the critical path and can mask actual progress or delays in the schedule. Date constraints should be minimized because they restrict the movement of activities and can cause false dates in a schedule. They can also imply a false level of criticality because of their effects on float. Moreover, constraints affect the analysis of risk in the schedule. Hard constraints can sometimes be impossible to meet, given the network characteristics, and can thereby result in schedules that are logically impossible to carry out.

SNET constraints are valuable when an activity cannot start any earlier than a fixed date and has no other logical dependencies. They are often used to represent the availability of cash flow or reliance on some external product. For example, a production line may not be available until an outside entity finishes producing its product. In that case, an SNET constraint would legitimately prevent scheduled activities from unrealistically starting before they should.

SNET constraints are also used to signal the receipt of some item, such as a hardware subcomponent or a government-furnished test article. However, often these conditions of supply by an outside vendor or contractor are better represented as actual activities in the schedule. For

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example, the receipt of a subcontractor hardware component is often modeled as a milestone with an SNET constraint. It may be more appropriate to model this as one activity or a sequence of activities representing the whole procurement process, starting with the ordering of the product and ending with actual receipt. These types of representative activities—referred to as “reference” tasks or “schedule visibility” tasks—are not part of the project scope and have no assigned resources, yet they have the potential to affect project activities. For example, the time to produce the product should be represented by a fabrication activity. By modeling vendor or contractor production as an activity, the program office can track the high-level progress of the contractor and apply risk to the external production activity. Representing supplier, government, or subcontractor deliverables as date-constrained milestones rather than summary activities may understate the risk in the procurement process.

SNET constraints are also often used to delay activities in response to available resources, such as labor or funding. However, this model should not be used for several reasons. First, it prevents the constrained activity from dynamically taking advantage of possible time savings being produced by predecessor activities. Second, logical dependencies should not be used to allocate resources because, typically, resource-constrained activities that are resolved with date constraints are forced to occur sequentially. This may temporarily solve a specific resource overallocation, but the sequential logic will remain even if additional resources are assigned to the activities. Finally, perhaps the main disadvantage of applying SNET constraints to represent the availability of resources is that it requires constant manual upkeep of the schedule. Updating constraint dates on associated activities manually may be manageable in a relatively small schedule with a small number of resources. However, large schedules with hundreds of SNET constraints representing tens or hundreds of resources will quickly become unmanageable, and the likelihood of errors will increase. If decision makers are not aware that an unnecessary SNET constraint on a low-level detail activity is preventing the activity from starting earlier, additional opportunities for time savings will be lost.

As described in Best Practice 3, resources should be assigned to activities so that their availability can drive the dates of planned activities according to resource calendars. For example, suspensions to work because of weather events are most appropriately indicated by a nonworking period in the working calendar rather than date constraints. Updating resource calendars is easier to manage than manually updating hundreds of individual constraints (see case study 5).

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Case Study 5: Managing Resources with Constraints, from *DOD Business Transformation,* GAO-11-53

GAO's analysis of the Army's Global Combat Support System found that dependencies within the schedule were generally sound, but 60 percent of the activities (or 1,360) had Start No Earlier Than (SNET) constraints. SNET constraints are considered "soft" date constraints because they allow an activity to slip into the future if their predecessor activity is delayed, but the activity cannot begin earlier than its constraint date.

Program officials stated that SNET constraints were used to manually allocate resources and coordinate data tests, which relied on coordination with outside partners. Officials further stated that individual control account managers monitor these constraints. GAO found that 87 percent of the constraints were actively affecting the start date of their activities. That is, without the constraint, the activity might have been able to start sooner.

Constraining over half of all activities to start on or after specific dates defeats the purpose of a dynamic scheduling tool and greatly reduces the program's ability to take advantage of possible time savings.

GAO, *DOD Business Transformation: Improved Management Oversight of Business System Modernization Efforts Needed,* GAO-11-53 (Washington, D.C.: October 7, 2010).

More information on resources and calendars is given in Best Practices 3 and 4.

Finally, SNET and FNET date constraints that are not actively constraining an activity's start or finish date should be removed from the schedule. In these cases, the constraints are meaningless.

The hard MSO and MFO constraints prevent activities from moving either forward or back in the plan in response to the status of predecessor activities. This includes preventing the constrained activities from taking advantage of time savings from predecessor activities. In other words, even if the constrained activity could start earlier, it will not do so according to network logic because the early and late dates are set equal.

Placing a hard constraint on an activity fixes the date and immediately causes the activity to become critical. It is therefore possible to use hard constraints as a temporary working tool during schedule development to calculate total available float up to key milestones. The temporary use of hard constraints is also valuable for assessing the realism of available

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resources to achieve the planned activity date. For example, a hard constraint placed on an intermediate delivery milestone may show the need for an immediate “bow wave” of resources, shortening the predecessor durations because it is forcing the milestone to be achieved on an unrealistic date.

Hard constraints are useful for calculating the amount of float available in the schedule and, therefore, the realism of the required project finish date and available resources during schedule development. However, they may be abused if they force activities to occur on specific dates that are determined off-line without much regard for the realism of the assumptions necessary to achieve them. It is important to note that just because an activity is constrained in a schedule, the activity is not necessarily constrained in reality. A customer-mandated date, including contractual obligations, does not constitute a legitimate reason to constrain an activity. A schedule is intended to be a dynamic, pro-active planning and risk mitigation tool that models the project and can be used to track progress toward important project milestones. Schedules with constrained dates can portray an artificial or unrealistic view of the project and begin to look more like calendars than schedules. Such unrealistic views are especially dangerous when they are translated to higher-level summary schedules for decision makers’ use.

Senior management may not be aware that key milestone dates in the summary schedules are artificially fixed dates that are actually behind schedule in working-level detailed schedules. Working versions of schedules may include hard constraints to assess available float and available resources, but the baseline schedule and official status updates should not contain hard constraints. If a hard constraint cannot be avoided, it must be used judiciously and be fully justified by referring to some controlling event outside the schedule in the schedule’s baseline documentation.

In summary,

- SNET and FNET constraints delay activity starts and finishes even if predecessor durations allow them to occur earlier. These constraints allow activities to slip if their predecessors cause them to slip—in this case, they become meaningless and should be deleted. However, their use must be justified because, in general, program management’s not wanting to start or finish an activity as soon as possible may be questionable.

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- Because SNLT and FNLT constraints prevent activities from slipping, their use is discouraged. They should never appear in the schedule baseline. If they are not properly justified in working schedules, they must be immediately questioned.
- Because MSO and MFO constraints prevent activities not only from slipping but also from accelerating, their use is discouraged. They should never appear in the schedule baseline. If not properly justified in working schedules, they must be immediately questioned.

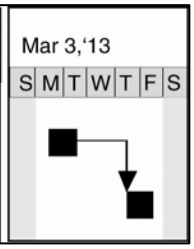
Many activities with date constraints are typically substitutes for logic and can mean that the schedule was not well planned and may not be feasible. In addition, constraints can cause misleading risk analysis results because they override network logic.

Lags and Leads

A lag in a schedule denotes the passage of time between two activities. Lags simply delay the successor activity—no effort or resources are associated with this passage of time. A common example of the use of a lag is the passage of time to allow concrete to cure, as in figure 14. The forms on the basement walls cannot be stripped until the concrete cures. While other work may be occurring in parallel in other parts of the house, this particular sequence of activities is delayed in order that the concrete can cure.

Figure 14: A Lag

Activity name	Start	Finish
Pour basement walls	3-4-13	3-5-13
Strip form for basement walls	3-7-13	3-8-13



Source: GAO.

Without the lag, work associated with stripping the forms may start as soon as the basement walls are poured. The lag delays the start of the successor activity to allow time for the concrete to cure.

A negative lag, known as a lead, is used to accelerate a successor activity. In figure 15, installing the rebar in the basement walls is accelerated to begin 1 day before the forming of the walls is finished.

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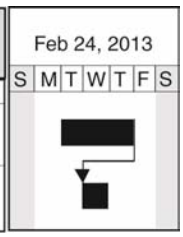
Figure 15: A Negative Lag (or Lead)

Activity name	Start	Finish
Form basement walls	2-26-13	2-28-13
Install rebar in basement walls	2-27-13	2-27-13



Source: GAO.

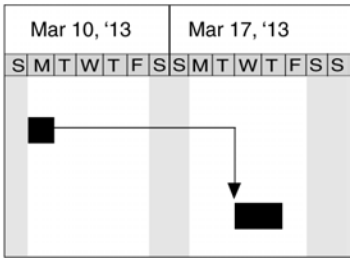
Without the lead, installing rebar would start as soon as the basement walls have been formed. The lead accelerates the start of the rebar installation activity and allows the forming of the walls and the installation of the rebar to overlap 2 days before formation of the walls is completed. If this is possible, the project might finish ahead of schedule.

Using Lags

Like constraints, lags have a specific use in scheduling but may be abused. Because lags denote the passage of time and leads denote the acceleration of a successor relationship, they are often misused to force successor activities to begin on specific dates. For example, if the general contractor has mandated that the installation of floor joists and decking must start on March 20, yet its predecessor activity finishes on March 12, a 6-working day lag will force the installation activity to occur later than necessary (see figure 16).

Figure 16: Using a Lag to Force an Activity's Start Date

Activity name	Start	Finish
Set steel columns and beams	3-11-13	3-11-13
Install first floor joists and decking	3-20-13	3-22-13



Source: GAO.

The lag in the example lessens the ability of the project schedule to dynamically respond to changes in the status of predecessor activities. A lag is static; that is, the lag will always be 6 days long unless the scheduler manually changes it. As shown in figure 17, if the predecessor activity slips 1 day, the 6-day lag forces the mandated event to occur 1

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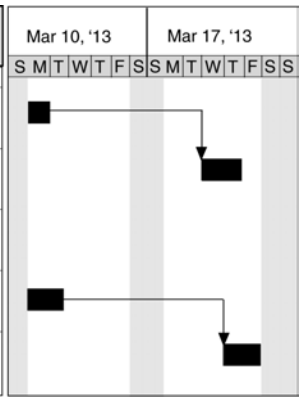
working day later than March 20. For the event to occur on March 20, the lag must be changed to 5 days.

Figure 17: The Effect of a Lag on Successor Activities

Activity name	Duration (in days)	Start	Finish
Set steel columns and beams	1	3-11-13	3-11-13
Install first floor joists and decking	2	3-20-13	3-21-13
Set steel columns and beams	2	3-11-13	3-12-13
Install first floor joists and decking	2	3-21-13	3-22-13



Source: GAO.

Constant manual updating defeats the purpose of a dynamic schedule and is particularly prone to error when the schedule contains many lags. If for some compelling reason outside the schedule joists and decking installation cannot start before March 20, the better approach would be to put the SNET constraint there. Hence, that date will be maintained unless its predecessor is delayed past March 20, and then the activity will by logic be pushed to a later date.

Lags, like date constraints, must be used judiciously. They represent a real need to delay or quicken time between two activities. They must be justified by compelling reasons outside the schedule in the schedule documentation. In particular, F–S relationships with lags are generally not necessary. In these cases, every effort should be made to break activities into smaller tasks and to identify realistic predecessors and successors so that logic interface points are clearly available for needed dependency assignments. If used improperly, lags can distort float calculations in the schedule and corrupt the calculation of the critical path. Lags are useful in summary and intermediate schedules because portions of long-term effort are likely to be unknown, or one may wish to reduce the number of activities displayed in high-level reports. Lags are usually used in places where detail is not sufficiently broken down to identify the needed interface points for making proper relationships, as in early summary-level schedules.

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But lags must not be used in the place of effort in detailed schedules because lags take no resources. Likewise, lags should not be used to represent procurement activities or other types of work performed by parties external to the schedule. Because lags are static and simply denote the passage of time, they cannot be updated with progress, are not easily monitored, and do not respond to the availability of resources.

Lags are also often used as buffers between two activities for risk; however, this practice should be discouraged because the lags persist even as the actual intended buffer is used up.

Using Leads

Leads in particular are often unnecessary. As negative lags, leads imply the unusual measurement of negative time and exact foresight about future events. In the example in figure 15, management must assume some prescient knowledge to start installing rebar 1 day before wall forming finishes. Any delay in forming the walls within the last day may cause immediate problems for the plan. A 2-day look ahead might seem trivial, but leads of weeks or even months are common in some schedules, causing a credibility problem when people are forced to see that far into the future on a risky project. In effect, a lead indicates that a future event will dictate the timing of an event in the past—a situation that is neither logical nor possible.

The concept of a lead is better represented by a positive lag on an S–S relationship or, even more straightforward, F–S relationships with no lags using smaller-duration activities. For example, instead of a lead, the wall-forming activity should be broken down into smaller activities to identify the proper F–S activities. For example, the wall-forming activity might be broken into two sequential subactivities: “form east and west basement walls” and “form north and south walls.” “Install rebar in basement walls” could then be linked with a finish-to-start relationship to “form east and west walls,” as shown in figure 18.

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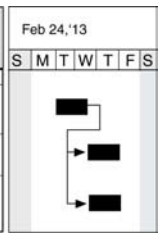
Figure 18: Eliminating Leads with Finish-to-Start Links

Activity name	Start	Finish
Form east and west basement walls	2-26-13	2-27-13
Form north and south basement walls	2-27-13	2-28-13
Install rebar in basement walls	2-27-13	2-28-13



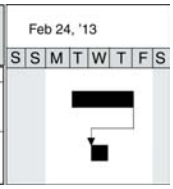
Source: GAO.

The network now clearly shows that once the east and west walls have been formed, rebar installation can begin. It also clearly identifies that rebar installation can go on while the last two walls are being formed. Any delay in forming the last two walls will still delay rebar installation, but the sequence of events and delay's effects are now obvious to anyone not intimately familiar with the project.

Finally, using leads improperly can cause logic failures when a lead is longer than the successor activity. An example is given in figure 19.

Figure 19: Logic Failure Associated with a Lead

Activity name	Start	Finish
Form basement walls	2-26-13	2-28-13
Install rebar in basement walls	2-27-13	2-27-13



Source: GAO.

The finish-to-start link in figure 19 between "form basement walls" and "install rebar in basement walls" dictates that forming walls must finish before installing rebar can begin. Suppose the relationship also has a 2-day lead that states that the installation of rebar should begin 2 days before forming the basement walls is finished. However, installing rebar takes only 1 day, which means the installation of rebar in the basement walls will actually finish before the basement walls are formed. This causes a conflict in logic between the lead and the finish-to-start relationship. Moreover, because the lead causes rebar installation to finish a day earlier than the forming of basement walls, an artificial day of float may be introduced into the sequence of activities.

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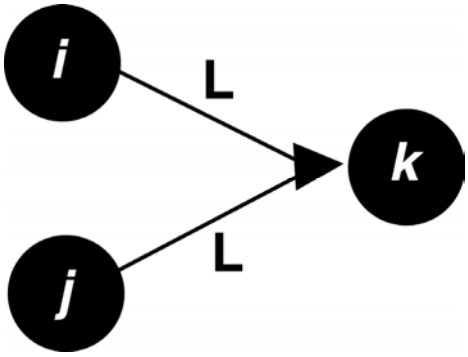
Note that the number of activities affected by a lag or lead is different from the total number of lags or leads in the schedule. The total is useful for determining the extent to which updating the schedule will be affected by the use of lags and leads. As stated above, a major disadvantage of lags and leads is that they are static; if they are prevalent in the schedule, the update process requires significant manual effort and becomes time consuming and prone to error.

The total number of predecessor relationships with a lag or lead provides a scheduler with a sense of how cumbersome the update process will be. If the schedule is not well maintained, its utility as a dynamic management tool will be greatly reduced and activity dates may be artificially delayed by a static lag or lead. For this reason, it is also worthwhile to understand the number of activities that will actually be affected by such a situation. For example, if an activity has two predecessors, each with a lag, only one predecessor will drive the outcome of the activity. Thus, while two activities, i and j, have lags in this scenario, only one activity's schedule date, k, would be affected as an out-of-date lag. This situation is illustrated in figure 20, where "L" denotes a lagged successor.

Figure 20: Enumerating Lags



Source: GAO.

Path Convergence

Several parallel activities joining with a single successor activity is known as path convergence. Path convergence can represent an unrealistic plan because it implies the need to accomplish a large number of activities on time before a major event can occur as planned. The convergence of

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many parallel activities into a single successor—also known as a "merge point"—causes problems in managing the schedule.[11]

These points should be a key program management concern because risk at the merge point is multiplicative. That is, because each predecessor activity has a probability of finishing by a particular date, as the number of predecessor activities increases, the probability that the successor activity will start on time quickly diminishes to zero. Path convergence is the basis of "merge bias," which we discuss in detail in Best Practice 8.

Because of this risk effect, activities with a great many predecessors should be examined to see if they are needed and if alternative logic can be used to link some predecessors to other activities. Often paths converge because major milestones are used to "tie off" many predecessor activities, some of which may be only marginally related to the actual milestone. In this case, predecessor activities should be examined for available float. If many of the predecessors leading to the merge point have large amounts of float available, then convergence may not be an immediate issue. However, if several predecessor activities are determining the date of the successor event, then the workflow plan should be reexamined for the realism of performing many activities in parallel with the available resources.

The appropriate number of converging activities varies by project. A reasonable number of parallel activities for a large project will not be the same as for a small project. Because most work is performed serially, the majority of the schedule activities should have F–S relationships, resulting in a waterfall approach to the work. An excessive number of parallel relationships can indicate an overly aggressive or unrealistic schedule.

Best Practices Checklist: Sequencing All Activities

- The schedule contains complete network logic between all activities so that it can correctly forecast the start and end dates of activities within the plan.
- The majority of relationships within the detailed schedule are finish-to-start.

[11]Parallel lines do not converge in mathematics. However, in scheduling parlance, paths and activities are parallel if they occur in the same work periods. The paths converge when their activities have the same successor.

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- Except for the start and finish milestones, every activity within the schedule has at least one predecessor and at least one successor.
- Any activity that is missing predecessor or successor logic—besides the start and finish milestones—is clearly justified in the schedule documentation.
- The schedule contains no dangling logic. That is,
  - Each activity (except the start milestone) has an F–S or S–S predecessor that drives its start date.
  - Each activity (except the finish milestone and deliverables that leave the project without subsequent effect on the project) has an F–S or F–F successor that it drives.
- The schedule does not contain start-to-finish logic relationships.
- Summary activities do not have logic relationships because the logic is specified for activities that are at the lowest level of detail in the schedule.
- Instead of SNET constraints, conditions of supply by an outside vendor or contractor are represented as actual activities in the schedule.
- Date constraints are thoroughly justified in the schedule documentation. Unavoidable hard constraints are used judiciously and are fully justified in reference to some controlling event outside the schedule.
- Lags are used in the schedule only to denote the passage of time between two activities.
- Instead of lags and leads, every effort is made to break activities into smaller tasks to identify realistic predecessors and successors so that logic interfaces are clearly available for needed dependency assignments.
- If included in the schedule, lags and leads are used judiciously and are justified by compelling reasons outside the schedule in the schedule documentation.
- The schedule is assessed for path convergence. That is, activities with many predecessors have been examined to see whether they are needed and whether alternative logic can be used to link some predecessors to other activities.

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Best Practice 3: Assigning Resources to All Activities

Best Practice 3: The schedule should reflect the resources (labor, materials, overhead) needed to do the work, whether they will be available when needed, and any funding or time constraints.

A resource is anything required to perform work. Because resource requirements directly relate to an activity's duration, assigning resources to activities ensures that they will be used to determine realistic and rational activity durations. Because labor, material, equipment, burdened rates, and funding requirements are examined to determine the feasibility of the schedule, resources provide a benchmark of the project's total and reporting-period costs.

The process of assigning labor, materials, equipment, and other resources to specific activities within the schedule is known as loading resources. A resource-loaded schedule therefore implies that all required labor and significant materials, equipment, and other costs are assigned to the appropriate activities within the schedule. The schedule should realistically reflect the resources that are needed to do the work and—compared to total available resources—should determine whether all required resources will be available when they are needed. Loading resources is the first step in allocating the expected available resources to a schedule at the time an activity is planned to be performed. An analyst must examine resources by time period to determine whether they are adequate. To represent the total and reporting-period costs of the project, all resources (including subcontracts and LOE management resources) must be included. A schedule that has not been reviewed for resource issues is not credible.

Resources, Effort, and Duration

The amount of available resources, whether labor or nonlabor, affects estimates of work and its duration, as well as resources that will be available for subsequent activities. Labor is, of course, a human resource; nonlabor resources can be subcontracts, consumable material, machines, and other purchased equipment. Labor and equipment are measured in units of time such as hours and days; material resources are measured in cubic feet, tons, pallets, or the like. Resources can depend on time—generally labor but also equipment or space rented per period—meaning that they increase in cost as time runs longer. Alternatively, they can be time-independent in the sense that they cost the same regardless of time—for example, material costs. Some activities use both labor and nonlabor resources.

Labor Resources

In general, the amount of work, in person-days, required to complete an activity is equal to the duration of the activity multiplied by the number of labor resource units assigned. Stated another way, the duration of an activity is directly related to how much work is necessary to complete the

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activity divided by the number of people available to perform the work. However, this does not necessarily mean that doubling the available resources will halve the activity's duration.

If the amount of work is known, along with an estimate of the number of people available to perform that work, then its duration can be estimated, along with efficiency levels, risk, and other external factors. That is, when the amount of work is fixed, the number of labor resources directly affects its duration. For example, if an activity is estimated to require 16 hours of work (2 person-days) and only one full-time equivalent (FTE) employee is available to perform the activity within an 8-hour day, then the duration of the activity will be 2 days. If two FTEs are available to perform the activity, then the duration will be 1 day; if one FTE is available for only 50 percent of the time, the duration will be 4 days. Productivity or efficiency factors can be applied to specific resources to account for standard output rates, personal experience, or historical productivity. For example, a specific set of individuals in a resource group may have more experience performing an activity than other individuals in the same group. Productivity will vary depending on the type of work—for example, trees planted per day or drawings produced per week. Workflow will also affect productivity: a steady flow of work tends to increase efficiency, while a discontinuous flow will introduce inefficiencies.

The duration of other types of activities known as fixed-duration activities is not affected by the number of people assigned to perform the work. For example, the number of days required for testing a satellite in a vacuum chamber will be the same regardless of how many engineers are assigned to monitor the testing. Likewise, the duration of a management offsite meeting does not depend on the number of people who attend. In the case of fixed-duration activities, labor resource information is nonetheless vital because the number of people directly affects the work required for the activity and, therefore, the cost. For example, five engineers assigned to a 2-day fixed-duration software coding activity will incur 10 person-days of work at whatever labor rate each engineer earns.

Nonlabor Resources

Significant material and equipment resources should also be captured within the schedule. Material resources are consumables and other supplies that are used to complete the project. Equipment resources may be items such as machines that are installed during the project, which become part of the completed project at turnover. Other equipment resources facilitate project execution but are neither consumed nor turned over in the final product delivery—for example, a rented crane.

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Like labor resources, nonlabor resources can be fixed or variable. Fixed nonlabor resources do not vary with an activity's duration; that is, the same amount of resource is consumed regardless of the activity's duration. For example, 100 square feet of wood flooring might be needed for a floor, regardless of whether the floor construction takes 2 or 3 days to complete. Variable nonlabor resources may include equipment used during the project such as cranes or testing machines that are not consumed but provide services that vary with the duration of an activity. For example, the longer a testing activity runs, the longer the test equipment is in use.

Rolling Wave Planning

As discussed in Best Practice 1, a comprehensive IMS should reflect all activities of a program and recognize that uncertainties and unknown factors in schedule estimates can stem from, among other things, limited data. As such, a schedule incorporates different levels of detail depending on the information available at any point in time. That is, near-term effort will be planned in greater detail than long-term effort. Detailed activities within a low-level schedule represent work packages, or detailed tasks, that are typically 4 to 6 weeks long. These detail activities reflect near-term, well-defined effort, typically within 6 months to a year of the current date. Effort beyond the near term that is less well defined is represented within the schedule as planning packages.

Although some schedulers insist on scheduling detailed activities for the entire project, it is often difficult to forecast detailed work clearly beyond 9 to 12 months. Planning packages summarizing work in the distant future can be used as long as they are defined and estimated as well as possible. Planning packages are planned at higher levels such that a single activity may represent several months of effort, generic work to be accomplished by a trade or resource group, or even a future contract or phase.

As time passes and future elements of the program become better defined, planning packages are broken down into detailed work packages. This incremental conversion of work from planning packages to work packages is commonly known as "rolling wave" planning. Rolling wave planning continues for the life of the program until all work has been planned in detail. Rolling wave planning with portions of effort that align to significant program increments, blocks, or updates is known as "block planning." A best practice is to plan the rolling wave to a design review, test, or other major milestone rather than to an arbitrary period such as 6 months. Moreover, detail should be included in the schedule whenever

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possible. That is, if portions of far-term effort are well defined, they should be included in the IMS as soon as possible. However, care should be taken not to detail ill-defined far-term effort so soon as to require constant revision as time progresses.

While planning packages represent far-term effort that is not yet planned in detail, each planning package must still be traceable to WBS elements within the IMS. Moreover, planning packages should be logically linked within the schedule to create a complete picture of the program from start to finish and to allow the monitoring of a program's critical path. As durations and resource assignments are refined over time, so too is the detailed sequence of activities.

Loading Activities with Resources

Loading resources into a schedule helps management compute total labor and equipment hours, calculate total project and per-period cost, resolve resource conflicts, and establish the reasonableness of the plan. A schedule without resources implies an unlimited number and availability of resources. Fully loading the schedule with resources, including materials, equipment, direct labor, overhead, and level of effort activities, provides the basis for the performance measurement baseline (PMB), which can be used to monitor the project using earned value management (EVM).[12] Milestones should never be assigned resources because they have no duration. Assigning resources to milestones is an unfortunate common practice that greatly distorts resource hours worked.

Resource assignments and duration estimates will vary in detail depending on the level of detail of activities in the schedule. Work scheduled for the near term should account for specific resource availability and productivity. When a schedule is fully resource loaded, budgets for direct labor, overhead, and material are assigned to both work and planning packages so that total costs to complete the program are identified at the outset.

In addition, the level of detail for resource loading should be based on the information available to management as well as the purpose of the schedule. Detail schedules used for day-to-day management should

[12]For more information on the relationship between cost, schedule, and EVM, see *GAO Cost Estimating and Assessment Guide*, GAO-09-3SP, chs. 18 and 19.

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include detail resource information, while summary schedules with higher-level resource information may be more appropriate for analyses such as an integrated cost-schedule risk analysis. Non-LOE resources should not be assigned to summary activities because summary durations depend on the activities contained within them. However, lower-level resource information can be rolled up to the summary levels for reporting purposes.

Activity owners responsible for managing the day-to-day effort and the most experienced team members who will be performing the work are the best source of resource estimates. Activity owners must be able to explain the logic behind their resource estimates; if there is no justification for allocating and assigning resources, the schedule will convey a false accuracy. Estimated resources within the schedule should also reconcile with the life cycle cost estimate (LCCE). The assumptions for resources and related activity cost should be the same as those that are used in estimating activity duration. The basis of estimate (BOE) is the connection between cost and time and should be kept up to date as assumptions change. If durations, resources, or productivity rates change, the cost is also likely to change, and they need to be coordinated. Both the schedule and the LCCE should be thoroughly documented to include underlying resource assumptions for the entire estimated scope of work.

In terms of labor resources, a schedule can be loaded at different levels of detail, each level having its advantages and disadvantages. In some cases, a program may rely on a centralized resource pool, previously approved by management, that must be used as the detailed work schedules are populated. Assigning labor resources to activities at the name level (“Bob Smith Jr.”) is specific and allows management to track the effort of individual people and to make sure they are not overallocated. This is particularly useful for tracking the assignments and responsibilities of subject matter experts whose absence or overallocation could delay an activity. However, assigning individual names to activities requires constant updating and shuffling of assignments for vacations, sick leave, and the like and reduces flexibility in resource leveling. Individual name assignments may also require specific labor rates, although planners may simply enter the average rate for each employee to avoid this issue.

Assigning resources at the organizational level such as “agency test department” or “production facility staff” is quicker than assigning individual names to activities. However, organizations include multiple skill sets, which complicates allocating and assigning specific skill sets to activities. Assigning resources by skill set (“software engineer level 3”)

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may be more time consuming than organization-level assignments but is a compromise option for resource loading to avoid both too much and too little detail. Skill sets obscure specific labor rates, parse individuals' skills, and allow for management's easy rearrangement of individual personnel within skill sets.

Resource information can be stored within the schedule files or it can be stored externally in separate software. If resource information is stored and maintained outside the schedule, a clear process must exist for integrating information between the schedule and the resource management software. Specifically, managing resources outside the schedule requires a documented process by which resource assignments are fed back into the schedule so that it reflects the resolution of resource issues conducted separately. A best practice is to store the resource information in the schedule; otherwise, resource leveling will be difficult. Case study 6 provides an example of a fully resource-loaded schedule and its alignment to the program budget baseline.

Case Study 6: Assigning Resources to Activities, from *Nuclear Nonproliferation,* GAO-10-378

GAO assessed the extent to which the project schedule for the Department of Energy's Savannah River Waste Solidification Building used best practices. In addition to fully reflecting both government and contractor activities, the sequencing of 95 percent of the remaining 2,066 activities, and the establishment of a credible critical path driven by the logic of the schedule, the project's schedule included assigned labor and material resources that accounted for 98 percent of the project's $344 million cost baseline.

GAO, *Nuclear Nonproliferation: DOE Needs to Address Uncertainties with and Strengthen Independent Safety Oversight of Its Plutonium Disposition Program,* GAO-10-378 (Washington, D.C.: March 26, 2010).

Once the schedule is resource loaded, total resources in the schedule should be crosschecked with the program budget and contractual cost constraints. Crosschecking can be performed at the summary level by rolling up lower levels of the schedule to key high-level milestones. The cumulative resources and budget can be visualized graphically as a series of peaks and troughs of resource and funding availability. Resource peaks should be examined for feasibility regarding the available budget, availability of resources, and timeliness. For example, scheduled activities may call for 70 software engineers, but actual facility or administrative constraints may prevent the staffing of more than 40

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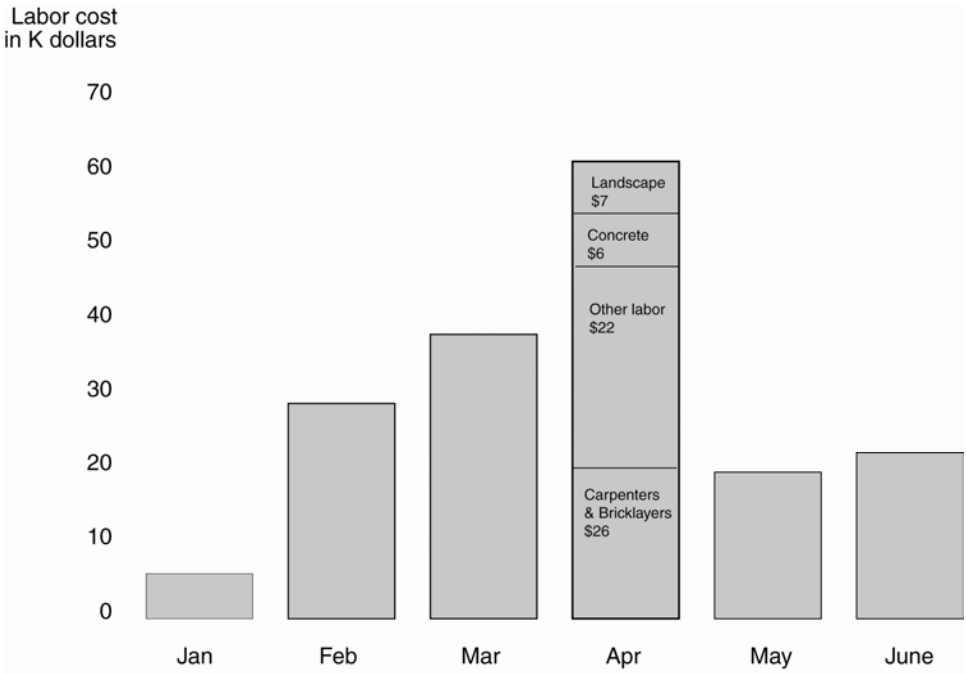
software engineers simultaneously. Peaks in the resource profile may also occur at incorrect times. For instance, resources should peak before major decision points in the program.

If the cumulative overlay of resources against major milestones shows resource peaks just beyond major milestone points, resources may have to be reallocated. In addition, managers and planners should assess whether “bow waves” exist in the high-level resource allocation profile. Bow waves represent the need for large amounts of resources near the end of work streams to finish deferred or delayed work in order to complete the project on time. Often the number of resources and funding required at the peak of a bow wave are unrealistic.

The benefits of using a schedule to reallocate resources can be seen in the example of house construction in figure 21.

Figure 21: A Profile of Expected Construction Labor Costs by Month



Source: GAO.

The expected labor costs peak severely in April, corresponding with a surge in carpentry and bricklaying work, as well as final grading, landscaping, and pouring concrete for the patio and sidewalks once the exterior house work is complete. The labor budgets then drop

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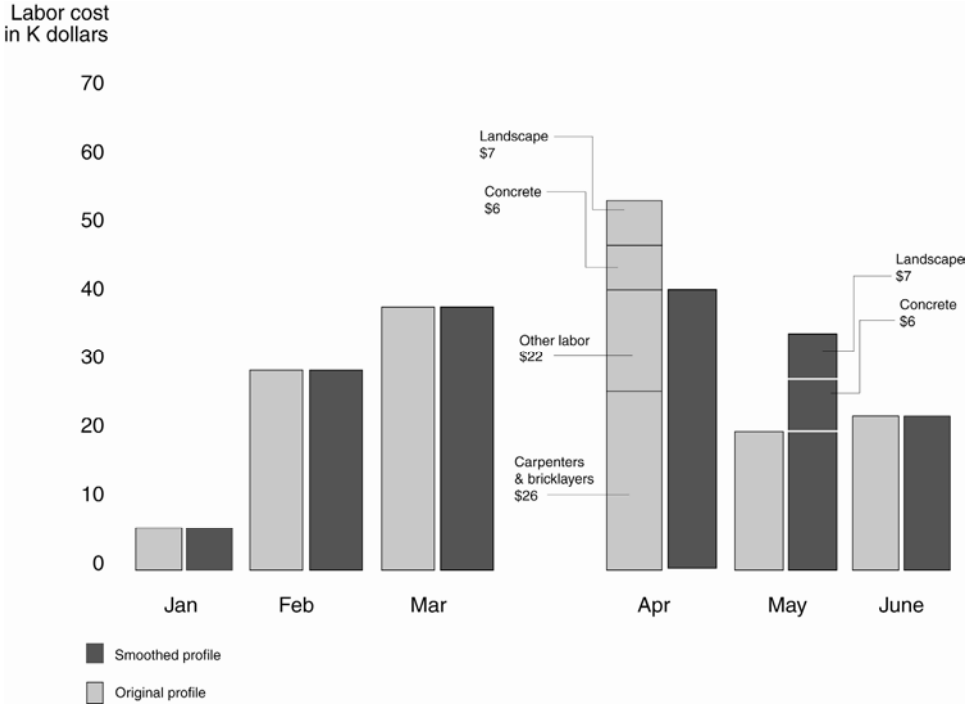
substantially for May and June, creating potential cash flow issues for the owners or the general contractor. However, final grading and landscaping need be completed only by the time of the owner's walkthrough, not scheduled until early July. Those activities have over 40 days of total float available; that is, the final landscaping and patio and sidewalk pouring activities can be delayed until May without delaying the owner's acceptance. This shifts nearly $10,000 in labor costs from April to May, easing the budget concerns in April and allowing work and cash flow to ramp down smoothly into June (see fig. 22).

Figure 22: A Smoothed Profile of Expected Construction Labor Costs by Month



Source: GAO.

Resource assignments should also be carefully reviewed for realism in light of assumptions made by the scheduling software. Depending on how resources are assigned and durations are estimated, the scheduling software may ignore resource overallocations by allowing assignments to continue beyond resource availability. For example, if only 3 carpenters are available to perform cabinetry work but 4 are assigned to the activity, the software may allow 4 carpenters and simply mark the activity as

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overallocated. In reality, a fourth carpenter is not available and the duration of the activity would have to be extended.

While resource loading the entire schedule may be a difficult exercise, it encourages management to assess the amount of resources available and encourages the discussion of difficult questions early in program planning. If the resource-loaded schedule alerts decision makers that the available resources will not suffice to execute the work on time as planned, management can begin negotiating for additional resources early in the program. Finally, linking available resources to activity durations may expose infeasible durations to scrutiny or show opportunities to reduce durations with the application of more resources. See Best Practice 4 for more information on establishing durations for activities.

Resource Leveling

Resource leveling adjusts the scheduled start of activities or the work assignments of resources to account for their availability. It is used primarily by the organization that has control of the resources to smooth spikes and troughs in resource demands created by the sequencing of activities in the schedule network. Frequent peaks and troughs in resource requirements represent their inefficient use because frequent mobilization and demobilization of resources is disruptive. For example, a schedule that requires 30 software engineers one week, none the next week, and 25 the next is disruptive and inefficient. A resource plan that is more manageable should be sought.

Leveling can be as simple as reassigning work from overallocated resources to underallocated resources or delaying the start date of activities until the resources required to perform the effort are available. Leveling may also develop into a complex trade-off between the required duration of the plan and the availability of myriad resources. Resource leveling can be performed automatically with scheduling software or manually by management and planners or both. Whatever the method, the goal of resource leveling is to finish the project on time or early, if possible, within a level of resources realistically expected to be available throughout the entire plan. Leveling resources allows management to identify “critical resources”—that is, resources that will delay the project finish date if they are not available for specific activities. Resource leveling is ideally integrated into scheduling and updating to ensure that the best possible trade-offs are made between resources and time and to ensure that the schedule remains credible throughout its lifespan.

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Typically, the activities that are delayed by resource leveling will be those with the most free float available and the least amount of assigned resources.[13] Resource leveling by shifting activities with free float minimizes the effect of the delayed activities on the project as a whole and minimizes the number of resources that must be reassigned work. Given the amount of float available in the schedule and the original assignment of resources, resource leveling can have little to no effect on a schedule, or it can severely delay the forecasted end date of the project. Resource leveling should be used only to reallocate resources to reduce spikes and troughs by absorbing available float. In other words, resource leveling should never delay a completion date. If the outcome of resource leveling is a delayed completion date, then resources are an inevitable constraint, and an alternative approach to the project plan is needed. If resources are assigned to activities realistically according to the sequence of planned activities and no resources are overallocated, then the resource-leveled scheduled will be the same as the original CPM schedule.

An example of resource leveling is given in figures 23 and 24. Figure 23 shows the sequence of events for selecting subcontractors for house construction, as scheduled according only to predecessor-successor logic. Once the owners select a general contractor, they can then confer with the general contractor to select the subcontractors: surveyor, excavator, concrete supplier, plumber, electrician, and the like. Once an individual subcontractor is selected, the owners and general contractor can then select and approve the necessary material. For instance, after selecting a plumber, the owners and general contractor can select the plumbing fixtures. From a network perspective, the selection of subcontractors can all happen at the same time once the general contractor is selected by the owner and, once each subcontractor is selected, the respective materials can be selected.

[13]Free float is the amount of time by which an activity can be delayed without affecting any successor (see Best Practice 7).

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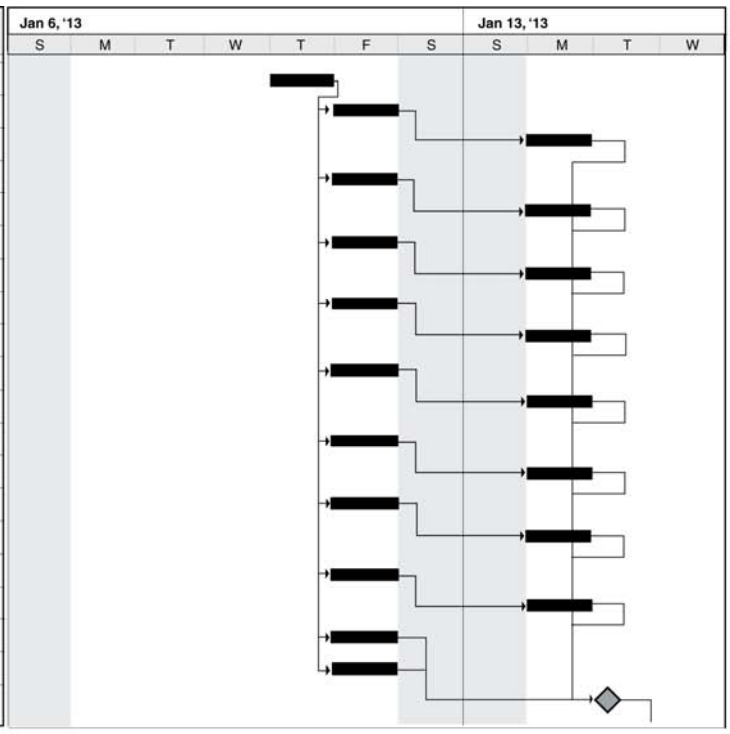
Figure 23: Resource Overallocation in a Correctly Sequenced Network

Task name	Start	Finish
Choose and hire general contractor	1-10-13	1-10-13
Choose and hire concrete contractor	1-11-13	1-11-13
Select and approve concrete equipment and materials	1-14-13	1-14-13
Choose and hire plumber	1-11-13	1-11-13
Select and approve plumbing equipment and materials	1-14-13	1-14-13
Choose and hire electrician	1-11-13	1-11-13
Select and approve electrical equipment and materials	1-14-13	1-14-13
Choose an HVAC contractor	1-11-13	1-11-13
Select and approve HVAC equipment and materials	1-14-13	1-14-13
Choose and hire roofer	1-11-13	1-11-13
Select and approve roofing equipment and materials	1-14-13	1-14-13
Choose and hire insulating contractor	1-11-13	1-11-13
Select and approve insulating equipment and materials	1-14-13	1-14-13
Choose and hire drywall and painting contractor	1-11-13	1-11-13
Select and approve drywall and painting equipment and materials	1-14-13	1-14-13
Choose and hire ceramic tile contractor	1-11-13	1-11-13
Select and approve tile equipment and materials	1-14-13	1-14-13
Choose and hire surveyor	1-11-13	1-11-13
Choose and hire excavator	1-11-13	1-11-13
Subcontractors selected and equipment and materials approved	1-14-13	1-14-13



	Thursday (1/10)	Friday (1/11)	Monday (1 /14)	Total hours
Owners (2)	8 hrs	80 hrs	96 hrs	184 hrs
General contractors (1)		20 hrs	40 hrs	60 hrs

Source: GAO.

However, once resources are assigned to the activities, it quickly becomes apparent that the plan is not feasible. The table below figure 23 gives the total hours necessary for two owners and one general contractor (GC).

The resource leveling of these activities is straightforward, because the owners and the general contractor have time available to select subcontractors while they wait for approval of the general construction permit. In fact, the “subcontractors selected and equipment and materials approved” milestone has nearly 18 days of free float. This allows management to spread the selection of subcontractors over the next several weeks without affecting activities succeeding the subcontractor selection milestone. Figure 24 shows the results of manual resource leveling for these activities.

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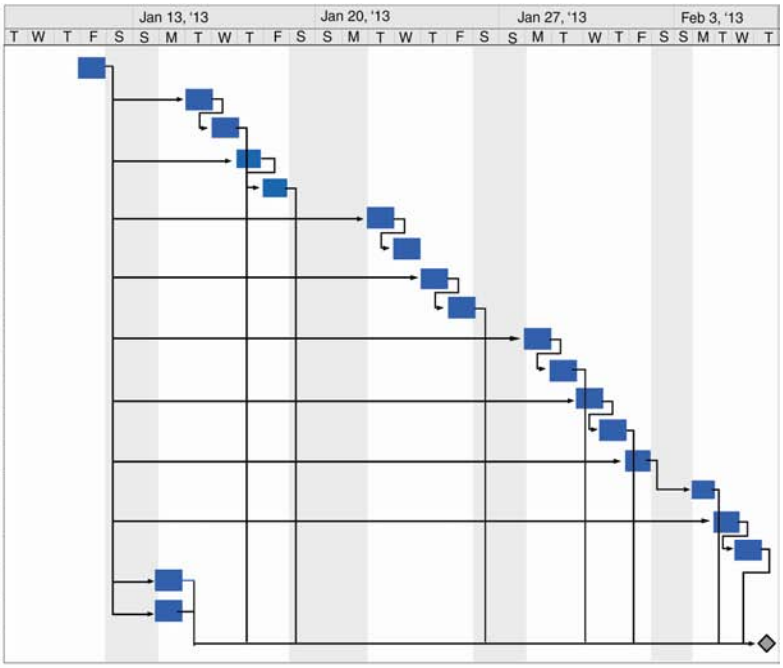
Figure 24: Resource Leveling in a Correctly Sequenced Network

Activity name	Start	Finish
Choose and hire general contractor	1-11-13	1-11-13
Choose and hire concrete contractor	1-15-13	1-15-13
Select and approve concrete equipment and materials	1-16-13	1-16-13
Choose and hire plumber	1-17-13	1-17-13
Select and approve plumbing equipment and materials	1-18-13	1-18-13
Choose and hire electrician	1-22-13	1-22-13
Select an approve electrical equipment and materials	1-23-13	1-23-13
Choose and HVAC contractor	1-24-13	1-24-13
Select and approve HVAC equipment and materials	1-25-13	1-25-13
Choose and hire roofer	1-28-13	1-28-13
Select and approve roofing equipment and materials	1-29-13	1-29-13
Choose and hire insulating contractor	1-30-13	1-30-13
Select and approve insulating equipment and materials	1-31-13	1-31-13
Choose and hire drywall and painting contractor	2-1-13	2-1-13
Select and approve drywall and painting equipment and materials	2-4-13	2-4-13
Choose and hire ceramic tile contractor	2-5-13	2-5-13
Select and approve tile equipment and materials	2-6-13	2-6-13
Choose and hire surveyor	1-14-13	1-14-13
Choose and hire excavator	1-14-13	1-14-13
Subcontractors selected and equipment and materials approved	2-6-13	2-6-13



	Week of 1/6	Week of 1/13	Week of 1/20	Week of 1/27	Week of 2/3	Total hours
Owners (2)	8 hrs	56	40 hrs	40	40	184
General contractors (1)		18	16 hrs	12	14	60

Source: GAO.

The activities are now spread over 5 weeks, leaving the owners and general contractor busy but not overallocated. This effort profile also frees the general contractor to work with other clients. Finally, the leveling of the subcontractor selection activities is done within the available free float, which does not affect either activities beyond the subcontractor selection milestone or the original critical path.

Because changes to the schedule from limited resource availability can alter float and critical path calculations, it is important that changes to resolve the resource conflicts be thoroughly documented and that

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everyone understands them.[14] Output from automatic resource-leveling routines should always be carefully examined by planners and management and tempered or adjusted where necessary. Automatic leveling may produce inefficient output, such as delaying activities if resources are partially available and, thus, prevent activities from being partially accomplished while the project waits for the full complement of resources to become available.

It is important to note that decisions made from incorrect data assumptions will themselves be incorrect. This is especially true if a CPM schedule is being overridden by resource-leveling decisions based on summary-level or incorrect resource assumptions. Resource leveling should occur only on detailed schedules that include detailed resource estimates supported by historical data and sound estimating methodologies. Without specific resource assignments, effects and costs cannot be accurately estimated and tracked. If a schedule is resource leveled, it is important to check the date of the last leveling against the date of the last changes to resources and resource availability. This will ensure that actual resource assignments have been aligned with the proposed leveling in the model.

Resource leveling should never be applied to summary schedules or when resources are specified at such a summary level that the concept of availability cannot be applied. Incorrect resource assumptions (usually in the form of unwarranted optimism) will lend unreasonable credence to a resource-leveled schedule, and the resulting leveled schedule will convey a false sense of precision and confidence to senior decision makers.

[14]Logic specifically inserted to solve resource leveling issues once the plan is baselined is known as “preferential logic” or “soft logic.” Preferential logic dictates a desired sequence of activities that is not entirely necessary. That is, the logic is not related to the work itself but reflects management’s plan for realistically executing the work. Conversely, “engineering logic,” or “hard logic,” dictates an order of activities that must occur regardless of preference. For example, concrete curing must always occur after pouring concrete. Inserting preferential logic to address resource leveling may be subject to the program’s schedule change control process.

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Best Practices Checklist: Assigning Resources to All Activities

- The amount of available resources, whether labor or nonlabor, affects estimates of work and its duration, as well as the availability of resources for subsequent activities.
- The schedule should realistically reflect the resources that are needed to do the work and—compared to total available resources—should determine whether all required resources will be available when they are needed.
- Resources are either labor or nonlabor, where labor refers to humans and nonlabor can refer to subcontracts, consumable material, machines, and other purchased equipment. Resources are identified as fixed or variable.
- Significant material and equipment resources are captured within the schedule along with other equipment resources that facilitate the project.
- Budgets for direct labor, overhead, and material are assigned to both work and planning packages so that total costs to complete the program are identified at the outset.
- If EVM is used to monitor the program, the fully loaded schedule, including materials, equipment, direct labor, overhead, and LOE activities, is the basis for the PMB.
- Activity owners are able to explain the logic behind their resource estimates.
- The same assumptions that formed resource estimates for the LCCE are applied to the estimated resources loaded into the schedule and are documented in the BOE. Underlying resource assumptions for the entire estimated scope of work are documented in the schedule baseline document at an appropriate level of detail.
- Resource information is stored in the schedule in the form of assignments. If resource management is performed outside the schedule, a documented process feeds resource assignments back into the schedule so that it reflects the resolution of resource issues conducted separately.
- Once the schedule is resource loaded, total resources in the schedule are crosschecked with the program budget and contractual cost constraints.
- Resource peaks are examined for the feasibility of the available budget, the availability of resources, and the timeliness of the peaks.
- If the cumulative overlay of resources against major milestones shows resource peaks just beyond major milestone points, resources may have to be reallocated.
- Managers and planners have assessed whether bow waves exist in the high-level resource allocation profile.

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- Resource leveling has been performed—that is, the scheduled time of activities or the assignment of resources has been adjusted to account for the availability of resources.
- In general, activities that are delayed through resource leveling have the greatest free float available and the least amount of resources assigned.
- If critical resources delay the entire project, changes to resolve the resource conflicts are thoroughly documented in the schedule narrative and understood by all.
- Planners and managers carefully examine and temper or adjust where necessary.
- Resource leveling occurs only on detail schedules that include detailed resource estimates supported by historical data and sound estimating methodologies.

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Best Practice 4: Establishing the Duration of All Activities

Durations

Best Practice 4: The schedule should realistically reflect how long each activity will take. When the duration of each activity is determined, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be reasonably short and meaningful and allow for discrete progress measurement. Schedules that contain planning and summary planning packages as activities will normally reflect longer durations until broken into work packages or specific activities.

Duration is the estimated length of time required to complete an activity—the time between its start and finish. Durations are expressed in business units, such as working days, and are subject to the project calendar. For example, for a standard 40-hour 5-day work week, the duration of an activity that starts on Thursday and ends on Tuesday will be 4 working days, even though it spans 6 calendar days. If the activity is assigned to a 7-day workweek calendar, then the activity will start Thursday and end Sunday. Multiple calendars can be created to accommodate activities with different work schedules.

The definition of duration is different from the definition of work (work is also referred to as effort in some scheduling software). For example, if a painting activity is scheduled for 2 8-hour days and two full-time painters are assigned to the job, the duration of the painting activity is 2 days, but the effort associated with painting is 32 hours (that is, two 8-hour employees for 2 days). Duration is directly related to the assigned resources and estimated amount of required work. Best Practice 3 discusses in detail how duration, resource units, and effort can change in relation to one another.

In general, estimated detail activity durations should be shorter than 2 working months, or approximately 44 working days, for near-term effort. Durations should be as short as possible to facilitate the objective measurement of accomplished effort. It may be difficult for management to gauge progress on detail activity durations that are too long. The shorter the duration of the detail activity, up to a point, the more precise the measurement of accomplished effort will be.

Planners should break long durations into shorter activities if logical breaks can be identified in the work being performed. If it is not practical to divide the work into smaller activities or insert intermediate milestones, justification for long durations should be given in the schedule baseline document. One rule of thumb is to break long activities into enough detail that finish-to-start logic relationships can be identified. Moreover, shorter durations are needed for areas of work associated with high cost or high risk.

However, durations that are too short and durations that are too long should be balanced. Very short durations, such as 1 day or less, may imply that the schedule is too detailed and require more frequent schedule duration and logic updates than necessary. Moreover, for a large number of 1- and 2-day duration activities, planners should recognize that people are rarely, if ever, 100 percent productive during an

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8-hour day. An actual “pure” productive workday is approximately 60 to 80 percent of an 8-hour workday, because time may be taken up with staff meetings, phone calls, e-mails, and water cooler talks. Also, a long chain of 1-day activities may be assigned to one employee who is assumed to never get sick or take vacation. It is important that activity durations remain realistic. Durations should not be broken up simply to meet an artificial guideline. If the work required for the activity is estimated to span 48 or 50 days, or if network logic dictates a duration longer than 44 days for some other reason, then the activity duration should reflect this reality.

Certain activities within schedules will naturally span more than 44 working days. For summary-level schedules, often created before detailed engineering is complete, durations might be longer than 44 days and lags might be more common. Within detailed schedules, LOE activities such as management and other oversight activities depend on the duration of the underlying discrete effort, so they span complete phases or even the entire project. LOE activities should be clearly marked in the schedule and should never appear on a critical path.

In addition, planning packages representing undefined future work can be several months long. However, the duration of the planning packages must be estimated and they should still be integrated into network logic.

Finally, all activity durations in the schedule should be defined by the same time unit (hours, days, weeks) to facilitate calculating and monitoring the critical path. Days are the preferred time unit.

Estimating Durations

Activity durations should be realistic to ensure that forecasted project delivery dates and critical paths are reliable. Activity durations are often mistakenly determined solely by the time available to complete the project. However, activity durations should be based on the effort required to complete the activity, the resources available, and resource efficiency or productivity. This ensures that the dates in the schedule are determined by the project plan logic and durations rather than wishful thinking or estimates that are constructed to meet a particular finish date objective.

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If the estimated durations and supporting schedule network logic do not support the target deliverable date, then the project manager and the teams must discuss how to realistically compress the schedule, perhaps by adding more resources, adjusting scope, or setting a later finish date.[15]

Activity durations should be estimated under normal conditions, not under optimal or "success-oriented" conditions or padded durations. "Normal conditions" for estimated durations imply that duration estimates do not contain padding or buffer for risk. Rather, risk buffers should be introduced as separate schedule contingency activities to facilitate proper monitoring by management, as discussed in Best Practice 8. Durations also should not be unrealistically short or arbitrarily reduced by management to meet a project challenge.

Activity owners should be responsible for estimating durations for their activities. Activity owners may have experience from similar activities on past projects that can help them estimate the duration estimate of the current activity. If the scheduler creates estimates, it is important that the underlying assumptions are acceptable to the activity owners.

All assumptions related to activity duration estimates should be documented at an appropriate level of detail, such as recording the methodology used to create the estimate (for example, parametric analysis of historical data or analogy to similar effort) and all supporting historical or analogous data. Documenting the basis for duration facilitates the communication of expectations between activity owners and decision makers and helps in estimating future analogous activity durations. Greater activity detail might be necessary when additional risk penetration and analysis will help management understand and address the implications of risk and uncertainty.

Finally, activity duration estimates for a WBS element in the schedule should clearly map to and correspond with the basis of the cost estimate for the same WBS element. For example, assumptions for the number of FTE workers underlying the cost estimate for a WBS element should also underlie the duration estimates for the WBS element in the schedule.

[15]Usually biased estimating has the purpose of achieving an earlier project finish date, often to satisfy management or the customer. That is, the direction of the estimating bias is typically not symmetrical.

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As discussed in Best Practices 1 and 3, a comprehensive IMS reflects all activities of a program yet incorporates different levels of detail, depending on the information available at any point in time. Detailed activities reflect near-term, well-defined effort while less well-defined effort beyond the near term is represented within the schedule as planning packages. Resource assignments and duration estimates will vary in detail concordant with the level of detail of activities in the schedule. The durations of detail activities within a low-level schedule represent work packages that are typically 4 to 6 weeks long. These duration estimates should be related to the amount of work required, specific resource availability, and resource productivity. Long-term planning packages naturally have less-accurate resource availability and productivity information from which to estimate durations because they can be several months or years long. Estimates for the durations of planning packages are most likely to be based on analogies to historical projects, planners' experience, or standard productivity rates.

Calendars

Calendars in schedules specify valid working times for resources and activities. Typically, resources are assigned to calendars to define their availability. The availability of a resource in turn affects the dates and elapsed duration of the activity to which it is assigned. Activities should be directly tied to task calendars, which will define the valid times the activity can be worked. Calendars are defined by the number of workdays per workweek as well as the number of hours available each workday. Special nonworkdays, known as exceptions, are defined in resource and activity calendars. Holidays and plant shutdown periods are examples of exceptions at the activity calendar level.

As we learned in Best Practice 2, the proper use of resource and task calendars usually precludes the need for soft constraints in schedules. For example, an SNET constraint may be used to prevent a testing activity from beginning too soon while the testing facility is in use for an unrelated project. Instead of an SNET constraint, however, the test facility should be defined as a resource within the schedule and assigned to a calendar whose exceptions represent days other projects are using the facility. If the testing facility becomes available sooner or later than originally planned, the scheduler need only update the exceptions within the testing facility resource calendar. Task calendars may also be employed to represent a suspension of effort. For example, if severe weather requires a suspension of concrete pouring, the activity can be assigned to a specific calendar that prevents the work from being performed on certain days.

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Another use for a resource calendar might be to exclude seasonal days from work. Outdoor construction probably cannot be conducted when the ground is frozen or the rain is intense. Such an activity could start before the rain or the freeze but would then have to continue after the end of the exception. A calendar that excludes November through February for bad weather could be assigned to all outdoor construction activities. Such dates are well known from many years of experience. Defining resource calendars in this way allows for properly scheduling activities automatically according to network logic. It also renders the SNET constraint unnecessary and eliminates the need for manual updates of the actual activity start date should the testing facility become available at a time other than planned. The automatic updating of the schedule will give greater confidence in float calculations and the derived critical paths. Resource calendars must also be adjusted for planned overtime—to allow a resource to work in an otherwise nonworking period.

Project managers must ensure that calendars are properly defined because schedules will incorrectly represent the forecasted start, finish, and durations of planned work if resources are assigned an incorrect calendar. A common mistake is to allow all activities within a schedule to simply adhere to the default calendar within the scheduling software. However, a default calendar rarely has appropriate national holidays defined as exceptions and will not define specific blackout periods or related exceptions. Similarly, the general project calendar that would have excluded holidays still may not represent the work practices of all resources. For instance, a testing facility may work 24 hours a day while some personnel work 4 10-hour days a week.

Additionally, if management has planned that work will be performed 7 days a week within the schedule, it is crucial that the people assigned to the planned activities are aware of the schedule. Planning effort can prevent unexpected delays in the project and the unnecessary use of schedule contingency. Establishing realistic calendars will provide for greater accuracy of dates and may reveal opportunities to advance the work.

Case study 7 shows how incorrect calendars can affect planned dates.

> Case Study 7: The Effect of Incorrect Calendars, from *Transportation Worker Identification Credential,* GAO-10-43
>
> The pilot schedule for the Department of Homeland Security's Transportation Worker Identification Credential program included

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duration estimates for all activities, but GAO could not be certain of their reliability. Nearly 86 percent (259 of 302) of the activities identified in the schedule were assigned to a 7-day calendar that did not account for holidays.

While pilot sites may normally operate on a 7-day schedule, resources for conducting pilot activities such as installing readers and associated infrastructure such as cables and computers or analyzing the results of pilot data may not be available on weekends. By using a 7-day calendar, the schedule inaccurately indicated that approximately 28 percent more workdays were available each year than actually were available.

Best practices in project management include obtaining stakeholders' agreement with project plans, such as the schedule. Because the schedule was not shared with the individual pilot sites, responsible pilot officials had no opportunity to comment on whether the 7-day schedule matched available resources. Therefore, pilot participants may not have the resources, such as employees who can work on weekends, to meet pilot goals.

If an activity is defined as taking 60 days, or approximately 2 months using a 7-day calendar, the reality may be that participants work a 5-day workweek with the result that the activity takes approximately 3 months to complete—1 month longer than scheduled.

GAO, *DHS Transportation Worker Identification Credential: Progress Made in Enrolling Workers and Activating Credentials but Evaluation Plan Needed to Help Inform the Implementation of Card Readers,* GAO-10-43 (Washington, D.C.: November 18, 2009).

A best practice when considering the duration of activities around the U.S. holiday season (Thanksgiving through New Years' Day) is to recognize that productivity is generally low then and that many workers take extended holidays during this time.[16]

[16]Schedule risk analysis can handle this phenomenon with probabilistic calendars, where any day has less than a 100 percent chance of being a working day, with that percentage reflecting the historical experience of people taking time off during a holiday season.

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Best Practices Checklist: Establishing the Duration of All Activities

- Activity durations are directly related to the assigned resources and estimated work required.
- In general, estimated detailed activity durations are shorter than 2 working months, or approximately 44 working days.
- Durations are as short as possible, to a point, to facilitate the objective measurement of accomplished effort.
- Long durations should be broken into shorter activities if logical breaks can be identified in the work being performed. If it is not practical to divide the work into smaller activities or insert intermediate milestones, justification for long durations is provided in the schedule baseline document.
- Very short durations, such as 1 day or less, may imply a schedule that is too detailed and will require more-frequent updates to schedule duration and logic than is otherwise necessary.
- LOE activities are clearly marked in the schedule and do not appear on a critical path. They are scheduled as hammock or summary activities, so that their durations are derived from other discrete activities.
- All activity durations within the schedule are defined by the same time unit (hours, days, weeks). Days are preferred.
- Planning packages representing undefined future work should be integrated into network logic.
- Activity durations are estimated under normal conditions, not optimal or “success-oriented” conditions or padded durations. That is, “normal conditions” for estimated durations implies that duration estimates do not contain padding or buffer for risk. They should also not be unrealistically short or arbitrarily reduced by management to meet a project challenge.
- All assumptions related to activity duration estimates are documented at an appropriate level of detail, such as the methodology used to create the estimate (for example, parametric analysis of historic data or opinion of a subject matter expert) and all supporting historic or analogous data. Activity duration estimates for a WBS element in a schedule should clearly map to and correspond with the basis of the cost estimate for the same WBS element.
- Activity duration estimates for a WBS element in a schedule should clearly map to and correspond with the basis of the cost estimate for the same WBS element.
- Calendars are used to specify valid working times for resources and activities.

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Best Practice 5: Verifying That the Schedule Can Be Traced Horizontally and Vertically

Horizontal Traceability

Best Practice 5: The detailed schedule should be horizontally traceable, meaning that it should link products and outcomes associated with other sequenced activities. These links are commonly referred to as "hand-offs" and serve to verify that activities are arranged in the right order for achieving aggregated products or outcomes. The integrated master schedule (IMS) should also be vertically traceable—that is, varying levels of activities and supporting subactivities can be traced. Such mapping or alignment of levels enables different groups to work to the same master schedule.

Horizontal traceability demonstrates that the overall schedule is rational, has been planned in a logical sequence, accounts for the interdependence of detailed activities and planning packages, and provides a way to evaluate current status. Schedules that are horizontally traceable depict logical relationships between different program elements and product handoffs. Horizontally traceable schedules support the calculation of activity and milestone dates and the identification of critical and near-critical paths.

Horizontal traceability applies to both an individual project schedule and the entire IMS, which may consist of multiple files. A horizontally traceable IMS includes complete logic from program start to program finish and fully integrates the entire scope of work from all parties in the program. Horizontal traceability ensures that forecasted dates within the schedule will be determined by network logic and progress to date rather than by artificial constraints. Any logic errors in the summary, intermediate, and detailed schedules will make dates between schedules inconsistent and will cause managers and activity owners to differ in their expectations.

Detail activities, milestones, and planning packages in a horizontally traceable schedule are linked to one another, preferably through straightforward finish-to-start logic at the detailed level, to represent the required inputs and outputs in a planned effort. Milestones representing key decisions or deliverables should have each predecessor activity traced and validated to make certain that they are directly related to the accomplishment of the milestone.

In particular, "giver/receiver" (G/R) milestones, common when multiple schedules are linked to form the IMS, must be clearly identified and logically linked between schedules. Giver/receiver milestones represent dependencies between schedules, such as hand-offs between integrated product teams, delivery and acceptance of government-furnished equipment, and the like. For example, a production schedule may include "receiver" milestones from outside suppliers representing the delivery of material and "giver" milestones representing the delivery of the produced article to the testing team. Likewise, the test schedule will include a receiver milestone that represents the receipt of the production article. Key G/R milestones should be defined in the schedule baseline document.

A horizontally traceable schedule will dynamically reforecast the date of a key milestone through network logic if activities related to accomplishing it

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are delayed longer than scheduled. For example, if the duration of a key milestone's predecessor activity is much extended relative to available float, the date of the key milestone should slip. Activities whose durations are extended to 100 or 200 days but have no effect on key milestones should be examined for unrealistic or dangling logic.

Horizontal traceability is directly related to Best Practice 2, sequencing all activities (see case study 8).

> Case Study 8: Horizontal Traceability, from *Aviation Security,* GAO-11-740
>
> Issues with sequencing logic prevented the Electronic Detection System acquisition schedule from being fully traceable horizontally. Extending the duration of some key activities had no effect on future milestone activities. For example, increasing the duration of the "evaluate pricing" activity associated with the first contract award from 40 days to 500 days did not affect any of the three contract award dates. Similarly, extending the duration of the first contracting activity, "request decision to move forward with purchase," from 1 day to 90 days had no effect on any of the three contract award dates.
>
> GAO, *Aviation Security: TSA Has Enhanced Its Explosives Detection Requirements for Checked Baggage, but Additional Screening Actions Are Needed,* GAO-11-740 (Washington, D.C.: July 11, 2011).

Vertical Traceability

Vertical traceability demonstrates the consistency of data between different levels of a schedule—summary, intermediate, and detailed. When schedules are vertically traceable, lower-level schedules are clearly consistent with upper-level schedule milestones, allowing for total schedule integrity and enabling different teams to work to the same schedule expectations. In this way, management can base informed decisions on forecasted dates that are reliably predicted in detailed schedules through network logic and actual progress to date.

In addition, vertical traceability allows managers to understand the effect on key program and G/R milestones if their lower-level activities are delayed. An activity owner should be able to trace activities to higher-level milestones within intermediate and summary schedules. Even though their activities may be rolled into a higher-level milestone, responsible owners should be able to identify when and how their product affects the program.

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All levels of schedule data, from detailed through summary schedules, should be derived from the same IMS. Ideally, the same schedule serves as the summary, intermediate, and detailed schedule by simply creating a summary view filtered on summary activities or higher-level WBS milestones. Summary schedules created by rolling up the dates and durations of lower-level elements are inherently vertically integrated. Often the project schedule is represented in a completely different format, because of the presentation software, and special care is needed if representations are to be consistent with the detailed schedules.

If alternative presentation modes are used to represent the project schedule, the program management office should be able to demonstrate that this process is successful. It is important to note that vertical traceability is not simply the ability to collapse WBS elements within the same contractor schedule. Vertical traceability implies the ability of the contractor schedule to roll up into the overall program schedule, which includes government activities, other contractor schedules, and interfaces with external parties, even if constructed in a separate computer file or different software package. All a program's project schedule information, from the suppliers through the contractors and government agencies, should be collapsible into one overall IMS. The relationship between vertical traceability and common WBS is highlighted in case study 9.

> Case Study 9: Vertical Traceability, from *Immigration Benefits,* GAO-12-66
>
> GAO assessed the U.S. Citizenship and Immigration Services' (USCIS) Office of Information Technology schedule for its Transformation Program. Vertical integration was partially demonstrated in the schedule. While GAO was able to trace some activities between the transformation program and other USCIS high-level schedules, the WBS numbers across schedules did not match. For example, the WBS name and element number for the System Definition Review activity—a critical milestone necessary if detail planning were to continue—was not consistent across the Office of Information Technology, solutions architect, and USCIS master schedules. Without a standardized WBS, identifying activities across different schedules is hampered, if not impossible.
>
> GAO, *Immigration Benefits: Consistent Adherence to DHS's Acquisition Policy Could Help Improve Transformation Outcomes,* GAO-12-66 (Washington, D.C.: November 22, 2011).

Finally, vertical integration applies to all schedule data that are reported to and by program management. That is, schedule information such as

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forecasted dates, predecessor logic, and critical path activities reported to management should be rooted in and traceable to the actual program IMS.

Best Practices Checklist: Verifying That the Schedule Can Be Traced Horizontally and Vertically

- The schedule is horizontally traceable. That is, the schedule
  - depicts logical relationships between different program elements and product hand-offs and clearly shows when major deliverables and hand-offs are expected;
  - includes complete logic from program start to program finish and fully integrates the entire scope of work from all involved in the program;
  - includes milestones representing key decisions or deliverables with traced and validated predecessor activities to ensure that they are directly related to completing the milestone;
  - clearly identifies and logically links “giver/receiver” milestones between schedules that are defined in the schedule baseline document;
  - dynamically reforecasts the date of a key milestone through network logic if activities related to accomplishing the milestone are delayed;
  - is affected by activities whose durations are extended by hundreds of days;
  - includes giver/receiver milestones that are defined in the schedule baseline document
- The schedule is vertically traceable. That is, it
  - demonstrates that data are consistent between summary, intermediate, and detailed levels of the schedule, including dates that are frequently validated through a documented process;
  - allows activity owners to trace activities to higher-level milestones with intermediate and summary schedules;
  - allows lower-level schedules to be rolled up into the overall program schedule, which includes government activities, other contractor schedules, and interfaces with external parties.

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Best Practice 6: Confirming That the Critical Path Is Valid

The Critical Path

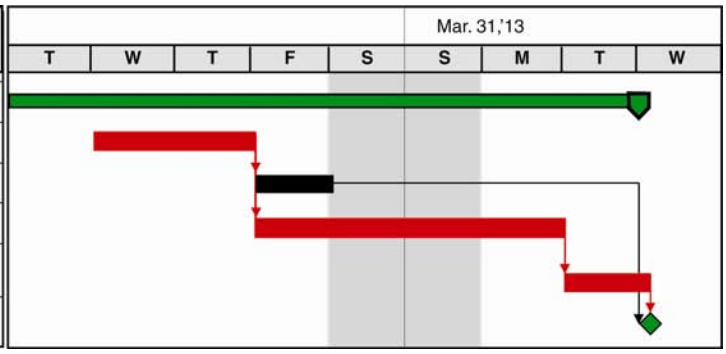
Best Practice 6: The schedule should identify the program critical path—the path of longest duration through the sequence of activities. Establishing a valid critical path is necessary for examining the effects of any activity's slipping along this path. The program critical path determines the program's earliest completion date and focuses the team's energy and management's attention on the activities that will lead to the project's success.

The critical path is generally defined as the longest continuous sequence of activities in a schedule. As such, it defines the program's earliest completion date or minimum duration. Activities on this path are termed "critical path activities." Typically, the sequence of activities with the longest total duration is also the path through the network with the lowest total float. As we shall see in Best Practice 7, total float is the amount of time an activity can slip before its delay affects the program end date. When the network is free of date constraints, critical activities have zero float, and therefore any delay in the critical activity causes the same amount of delay in the program finish date. That is, if an activity on the critical path is delayed by a week, the program finish date will be delayed by a week unless the slip is successfully mitigated. Therefore, the critical path is most useful as a tool to help determine which activities deserve focus and, potentially, management help.

In figure 25, the critical path is made up of three detail work activities: "install roof decking," "form and pour driveway," and "finish excavate and pour garage floor." "Install roof decking" has an estimated duration of 2 days, "form and pour driveway" 2 days, and "finish excavate and pour garage floor" 1 day. The minimum duration of this particular sequence of activities, leading up to the "framing complete" milestone, is therefore 5 days. An additional 1-day's activity, "rough-in framing inspection," is performed in parallel with "form and pour driveway"—that is, the rough-in framing inspection may start after the installation of the roof decking finishes, along with forming and pouring the driveway.

Figure 25: The Critical Path and Total Float

Activity name	Early start	Late start	Total float (in days)
Framing	3-11-13	3-11-13	0
Install roof decking	3-27-13	3-27-13	0
Rough-in framing inspection	3-29-13	4-2-13	2
Form and pour driveway	3-29-13	3-29-13	0
Finish excavate and pour garage floor	4-2-13	4-2-13	0
Framing complete	4-2-13	4-2-13	0



Source: GAO.

With the inspection complete and the garage floor poured, the framing portion of construction is considered complete. However, because "rough-in framing inspection" is 1 day shorter than "form and pour driveway" and

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does not affect the pouring of the garage floor, it does not directly affect the start date of the "framing complete" milestone. Notice that "rough-in framing inspection" has an early start of March 29 and a late start of April 2. In other words, rough-in framing inspection could start as late as April 2 (2 working days later than planned) and, if finished in 1 day, would have no effect on the "framing complete" milestone date of April 3. The difference between early and late dates for "rough-in framing inspection" yields 2 working days of total float. The early and late start dates for "form and pour driveway," however, are equal. If the driveway is formed and poured 1 day late, or if its duration extends by 1 day, then the "framing complete" milestone slips by 1 day. "Form and pour driveway" has zero float and is on the critical path.

Scheduling software automatically calculates a critical path through a network of activities by defining as critical those activities that have less than a predefined amount of total float. Typically, total float is set to zero, and the scheduling software marks critical all activities with zero or less-than-zero total float.

When the network is free of date constraints, activities with low total float are "near-critical" because they can quickly become critical if their float is used up in a delay. Near-critical paths need only a small extension of time to become critical. Management must monitor critical and near-critical activities through sound schedule management because any delay in them will delay the entire program. Near-critical paths are monitored according to a float threshold tailored to the project. For example, a brief schedule might consider a 5-day slip to be a near-critical threshold. In projects scheduled to take years, a 2- or 3-month's slip in near-critical paths might make the path critical. Because prolonging a schedule by 5 days on a short project is as easily possible as prolonging a multiyear project several months, project managers should manage all near-critical and critical paths.

The sequence of activities that make up the critical path changes as activities are delayed, finished early, occur out of planned sequence, and so on. Activities that were previously critical may become noncritical, and activities that were not critical may become critical. At any point in time, the critical path may or may not contain activities that management believes are particularly important. It is crucial that program management understand that an important activity is not necessarily "critical." A delay in an activity may be important for any number of reasons related to scope and cost without delaying the finish milestone date. In contrast, some mundane activities—training, for example—may be on the critical

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path and may not be particularly risky but can delay the project finish date if they take longer to accomplish. Similarly, an activity of long duration should not be referred to as a "critical path activity" simply because it will take a long time to accomplish. "Critical activity" in scheduling parlance has a specific definition that should be adhered to when reporting and evaluating schedule data.

The Critical Path and the Longest Path

The critical path is theoretically the sequence of activities that represents the longest path from the project's start and finish dates. In reality, however, as a schedule becomes more complex, total float values may not necessarily represent a true picture of the number of days an activity can slip. For example, multiple calendars, out-of-sequence progress, date constraints, and leveled resources can all produce misleading values of total float in complex schedules, leading to a misrepresentation of the sequence of activities that actually drives the project finish date.

As we noted in Best Practice 2, date constraints may cause activities to become critical, regardless of the total float that may be available if not constrained in the network. Specifically, backward-pass date constraints on activities other than the finish milestone will influence the criticality of activities. Hence, where constraints are many, there may be many more activities with zero or negative total float than activities that are actually driving the key project completion milestone.[17]

Figure 26 gives two sequences of activities necessary to complete framing: critical activities (in red) and noncritical activities (in black). The critical path is also the sequence of activities that represents the longest path to the "framing complete" milestone. Summing their duration yields 16 days. That is, the minimum duration from the start date of "install first floor joists and decking" to the "framing complete" milestone is 16 working days. A second path of activities, consisting of "exterior backfill basement walls" and "rough grade property," after the installation of the first floor joists and decking, has 7 days of available float and is therefore not considered critical.

[17]Negative float and its causes are discussed in detail in Best Practice 7.

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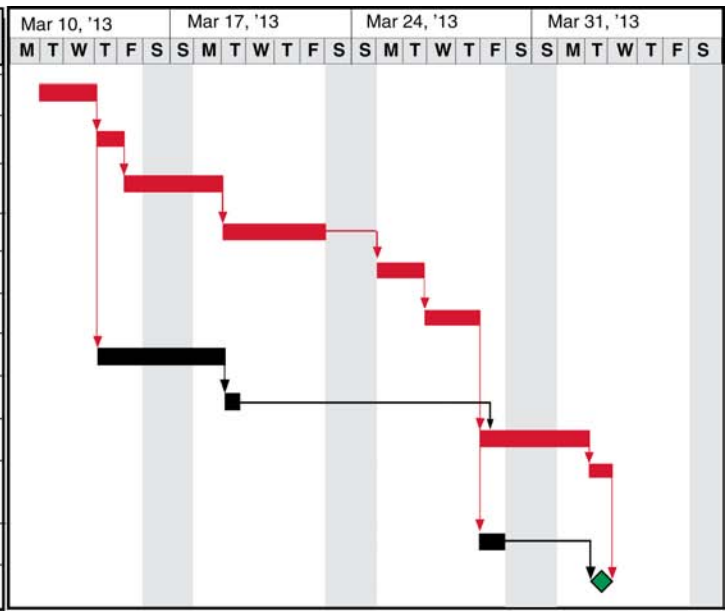
Figure 26: The Critical Path and the Longest Path

Activity name	Duration (in days)	Total float (in days)
Install first floor joists and decking	2	0
Install waterproofing on exterior basement walls	1	0
Finish excavate and pour basement floor	2	0
Frame first floor walls	4	0
Install roof trusses	2	0
Install roof decking	2	0
Exterior backfill basement walls	3	7
Rough grade property	1	7
Form and pour driveway	2	0
Finish excavate and pour garage floor	1	0
Rough-in framing inspection	1	2
Framing complete	0	0



Source: GAO.

If the general contractor were to introduce a backward-pass date constraint on “rough grade property”—mandating for example that the property be rough graded by March 19—then the date constraint on “rough grade property” would consume that path’s entire total float, redefining it as critical according to the total float criticality threshold of zero.

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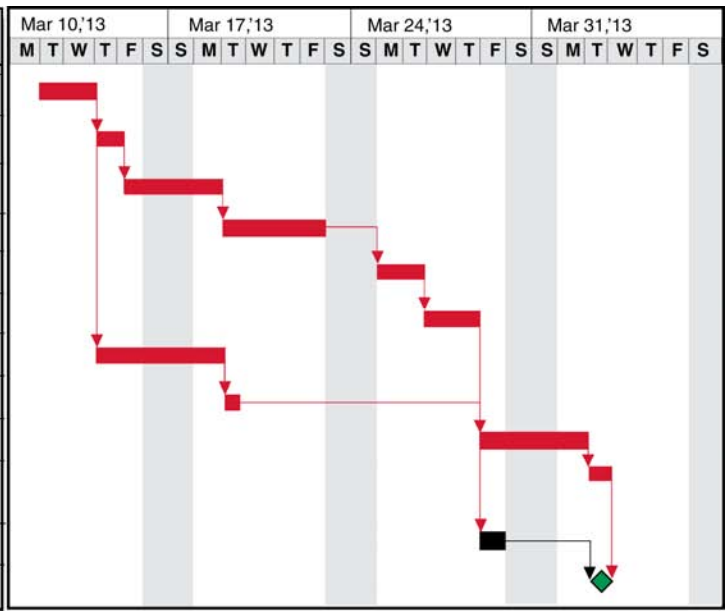
Figure 27: Critical Path Activities Not on the Longest Path

Activity name	Duration (in days)	Total float (in days)
Install first floor joists and decking	2	0
Install waterproofing on exterior basement walls	1	0
Finish excavate and pour basement floor	2	0
Frame first floor walls	4	0
Install roof trusses	2	0
Install roof decking	2	0
Exterior backfill basement walls	3	0
Rough grade property	1	0
Form and pour driveway	2	0
Finish excavate and pour garage floor	1	0
Rough-in framing inspection	1	2
Framing complete	0	0



Source: GAO.

The network now has two more critical activities than the network without the date constraint and shows two parallel critical paths in terms of total float. However, the longest path—in terms of duration—remains the same, regardless of the date constraint. While "rough grade property" is marked critical in the schedule, it actually has 7 days of relative float because it can slip 7 days before causing the "framing complete" milestone to slip. The longest path is also referred to as the driving path because it determines the date of the key milestone. A driving path can be identified for any key milestone or activity to determine the sequence of activities driving its finish date.

When the critical path is not the longest path, the longest path is preferred because it represents the activities that are driving the sequence of start dates directly affecting the estimated finish date, if we ignored the presence of date constraints. Therefore, rather than simply filtering on activities that are marked critical by the scheduling software, management should be aware of the activity "drivers" that are determining the schedule finish date.

Moreover, driver activities may or may not have the lowest total float values when activities other than the project finish milestone have date

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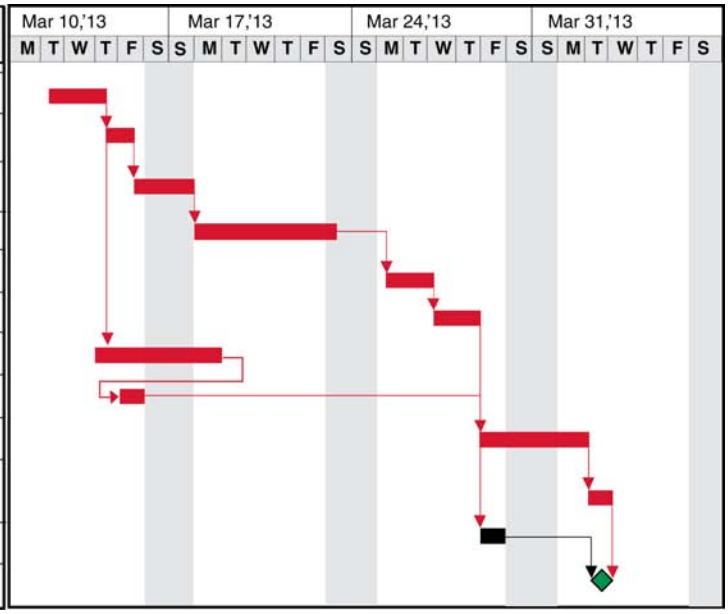
constraints. Continuing with the framing example in figure 27, suppose the general contractor mandates the property be rough graded by Friday, March 15. This mandate is reflected in figure 28.

Figure 28: The Longest Path and the Lowest-Float Path

Activity name	Duration (in days)	Total float (in days)
Install first floor joists and decking	2	-2
Install waterproofing on exterior basement walls	1	0
Finish excavate and pour basement floor	2	0
Frame first floor walls	4	0
Install roof trusses	2	0
Install roof decking	2	0
Exterior backfill basement walls	3	-2
Rough grade property	1	-2
Form and pour driveway	2	0
Finish excavate and pour garage floor	1	0
Rough-in framing inspection	1	2
Framing complete	0	0



Source: GAO.

The lowest total float path is now "exterior backfill basement walls," "rough grade property," "form and pour garage floor," and "finish excavate and pour garage floor." However, neither "exterior backfill basement walls" nor "rough grade property" is determining the finish date of the "framing complete" milestone. Most scheduling software calculates activity drivers along with the critical activities.

Common Barriers to a Valid Critical Path

As noted above, the critical path ideally represents the longest path, as when the schedule network is free of backward-pass constraints and activities on this path have the least float in the network. In this section, we highlight issues that prevent the critical path from being the longest path. When these issues arise, it is imperative that management recognize not only critical path activities—that is, activities with the lowest float—but also activities that are truly driving the finish date of key milestones.

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Calculating a critical path is directly related to the logical sequencing of activities. Missing or convoluted logic and artificial date constraints prevent the calculation of a valid critical path; they can cause activities to appear to be critical but that are not. Successfully identifying the critical path relies on a valid, credible schedule. That includes capturing all activities (Best Practice 1), proper sequencing of activities (Best Practice 2), horizontal traceability (Best Practice 5), the reasonableness of float (Best Practice 7), accurate status updates (Best Practice 9), and—if there are resource limitations—assigning resources (Best Practice 3).

It is essential that the critical path be evaluated before the schedule is baselined and after every status update to ensure that it is valid. If the schedule is missing activities, then the critical path will not be valid. Moreover, if the critical path is missing dependencies or has date constraints, lags, or level-of-effort activities or is not a continuous path from the current status date to the finish milestone, then it is not valid.

Continuous through All Activities

Unless the IMS represents the entire scope of effort, the scheduling software will report an incorrect or invalid critical path. As discussed in Best Practices 1 and 4, the IMS must include planning for all activities that have to be accomplished for the entire duration of the program. A critical path for one block, increment, or contract for a multiyear multiphased program is not a sufficient plan that can reliably forecast the finish date for the program. A critical path should exist for the entire program because detail activities, as well as long-term planning packages, must be logically linked within the schedule to create a complete picture of the program from start to finish. In addition, for projects under way, the longest path or critical path should start with at least one in-progress activity with an actual start date.

The critical path should be a continuous sequence of activities from the schedule status date to the finish milestone. In general, the sequence of activities should have no breaks and there should be no large gaps of unaccounted time. The critical path may branch off into several sequences of activities, but they must ultimately converge at the finish milestone. Sorting the schedule by activity start date, filtering by critical activities, and visually assessing the sequence of activities in a Gantt chart is an easy way to assess the practicality of the calculated critical path. Ideally, the Gantt chart will display a continuous waterfall of activities from the status date to the program finish date that are logically linked with finish-to-start relationships. Case study 10 shows why program-wide critical paths are important.

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Case Study 10: Noncontinuous Critical Path, from *FAA Acquisitions,* GAO-12-223

Officials from FAA's Collaborative Air Traffic Management Technologies system said that because of the 6-month spiral development approach, the program schedule could not deliver a single critical path for the entire program. Instead, the critical paths were by release. To produce the critical paths, the prime contractor used a constraint on the key deliverable finish milestone for each release.

At the time of GAO's analysis, officials stated that only work related to Release 5 was subject to a critical path analysis because that release was the current focus of management. GAO was able to trace a continuous critical path for Release 5, beginning with the project status date and ending with the Release 5 finish milestone. However, the validity of the Release 5 critical path was hampered by seven in-progress and remaining detail activities within Release 5 that had over 1,300 working days of total float. We also determined that a small number of activities outside Release 5 were under way (for example, activities related to other task orders). Because these activities fell outside the Release 5 task order, and therefore outside the purview of a Release 5 critical path analysis, management may not have been fully aware of the effect of any delay in these activities.

GAO, *FAA's Acquisitions: Management Challenges Associated with Program Costs and Schedules Could Hinder NextGen,* GAO-12-223 (Washington, D.C.: February 16, 2012).

Breaks in the critical path should be examined immediately and justified or otherwise addressed. Common causes of noncontinuous critical paths are that

- the start or finish date of an activity is driven by a constraint;
- a successor activity is driven by an unexplained lag;
- the start date of an activity is driven by an external predecessor;
- activities are scheduled according to different calendars, as when a predecessor activity ends in a nonworking period for the successor; and
- resource leveling is causing delays.

For example, if an activity on the critical path starts some days or weeks after its driving predecessor finishes (assuming finish-to-start logic) because of a start date constraint or an unexplained lag, then the path is considered to be noncontinuous and broken. In each scenario above, additional total float may occur in the predecessor activities; it would

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break the sequence of activities with zero total float. The program management team must determine whether this additional total float is meaningful. If it is not, the threshold for total float criticality may have to be raised.

The Number of Critical Activities

In general, assessing the quality of the critical path by predetermining the number of activities that should be critical is not useful. The number of activities on the critical path will depend on the visibility required to manage the program and reduce risk. However, if the ratio of critical path activities to the total activity count is nearly 100 percent, then the schedule may be overly serial and resource limited. Conversely, if only a few activities are on the critical path and they all represent LOE, then the critical path is being driven by supporting effort and will not identify effort that is driving key milestones.

Logical Sequencing

Float calculations are directly related to the logical sequencing of events (see Best Practice 7). Because float dictates the criticality of activities, the critical path is directly related to the logical sequencing of events and float calculations. If the schedule is missing dependencies or if activities are not linked correctly, float estimates will be miscalculated. Incorrect float estimates will result in an invalid critical path, hindering management's ability to reallocate resources from noncritical activities to those that must be completed on time. Errors or incomplete logic often cause values of total float that do not represent the state of the project schedule (we discuss this in Best Practice 7).

Date Constraints

We saw in Best Practice 2 that placing a hard constraint on an activity fixes the dates and immediately causes the activity to become critical. It is therefore possible to use hard constraints as a working tool while developing a schedule to calculate total available float up to key milestones. The temporary use of hard constraints is also valuable for assessing the likelihood that using available resources can achieve the planned activity date. However, using hard constraints simply to fix activity dates at certain points in time immediately convolutes critical path calculations and reduces the credibility of any schedule date on activities past the constraint in logic. In this case, the critical path is no longer the longest path; instead, each hard constraint in the schedule generates its own sequence of critical activities, and the purpose of CPM scheduling is defeated.

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Lags

The critical path should be free of lags; they obfuscate the identification and management of critical activities. As described in Best Practice 2, a lag is used in a schedule to denote the passage of time between two activities. Lags cannot represent work and cannot be assigned resources. Lags simply delay the successor activity, and no effort or resources are associated with them.

Lags are often misused to force successor activities to begin on specific dates. Evaluating a critical path that includes lags can therefore be difficult because the lag may or may not represent work that has to be accomplished by some resource, either internal or external to the program. In addition, because lags are not represented in a schedule as an activity, they can easily be overlooked as drivers of the finish milestone date. A lag that indicates a waiting period, such as for document review or materials delivery, should be replaced with an activity that can be actively monitored, statused, and perhaps mitigated if necessary.

In figure 29, “rough-in framing inspection” now has a 2-day lag on its finish-to-start relationship to the milestone “framing complete,” representing 2 days of paperwork that the general contractor’s company must perform. The total duration of “rough-in framing inspection,” including its lag, is 3 days. The activity becomes critical because the 2-day lag consumes its 2 days of total float. A report to the general contractor listing the current critical activities in the project would list “rough-in framing inspection” as critical but would more than likely fail to mention that its successor lag is causing it to be on the critical path, not the inspection activity itself. Any management initiatives by the general contractor to reduce the criticality of the inspection activity would fail, because it would be misdirected. The planned effort that is causing the criticality is concealed by the lag.

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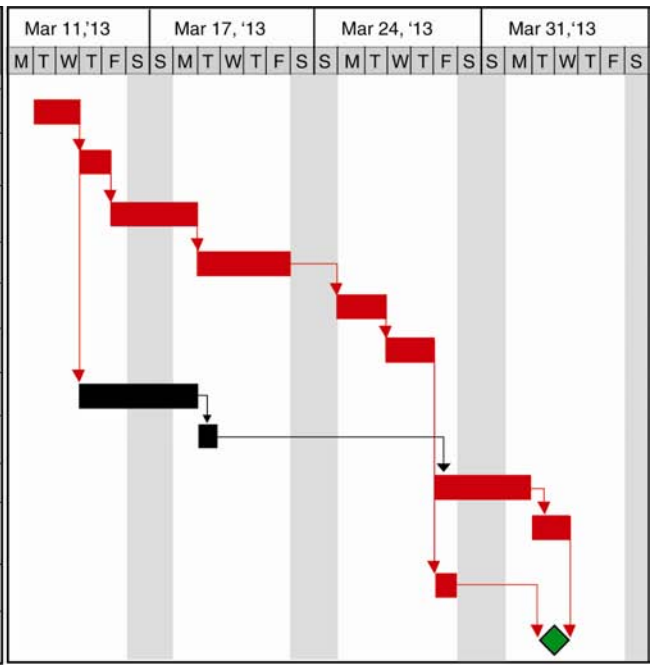
Figure 29: The Critical Path and Lags

Activity name	Duration (in days)	Total float (in days)
Install first floor joists and decking	2	0
Install water proofing on exterior basemant walls	1	0
Finish excavate and pour basement floor	2	0
Frame first floor walls	4	0
Install roof trusses	2	0
Install roof decking	2	0
Exterior backfill basement walls	3	7
Rough grade property	1	7
Form and pour driveway	2	0
Finish excavate and pour garage floor	1	0
Rough-in framing inspection	1	0
Framing complete	0	0



Source: GAO.

Level of Effort and Other Long-Duration Activities

We learned in Best Practice 1 that some schedulers represent LOE work by activities that have estimated durations rather than by hammock activities, the preferred practice. Their long durations mean that these activities may inadvertently define the length of a project and, thus, become critical if they are linked to successors through logic. A critical path cannot include LOE activities because, by their very nature, they do not represent discrete effort. The duration of LOE activities is determined by the overall duration of the discrete work they support. Therefore, an LOE activity cannot drive any successor and become critical. The logic should be placed on the detailed activities that the LOE resources support.

In the house construction framing example in figure 30, we see an overarching general contractor project management activity planned through April 3 to ensure that all framing activities are managed properly and all documentation is created and filed appropriately. However, the LOE project management activity now determines the minimum duration of the framing sequence of activities, rather than the sequence of actual work that has to be accomplished to achieve the completion of framing. It

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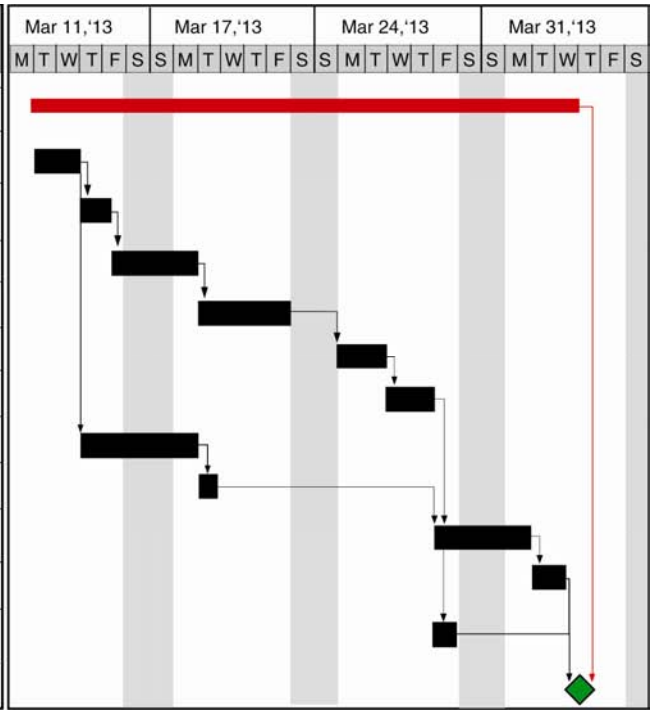
is impossible to reduce the duration of framing: adding resources to a level of effort activity simply increases the work. Using this schedule, management has no indication of which activities can slip and which will respond positively to additional resources and reduce the risk of finishing late.

Figure 30: The Critical Path and Level of Effort Activities

Activity name	Duration (in days)	Total float (in days)
Manage framing	17	0
Install first floor joists and decking	2	1
Install waterproofing on exterior basement walls	1	1
Finish excavate and pour basement floor	2	1
Frame first floor walls	4	1
Install roof trusses	2	1
Install roof decking	2	1
Exterior backfill basement walls	3	8
Rough grade property	1	8
Form and pour driveway	2	1
Finish excavate and pour garage floor	1	1
Rough-in framing inspection	1	3
Framing complete	0	0



Source: GAO.

Long-duration non-LOE activities in the detail planning period should be reevaluated to determine if they can be broken down into more manageable pieces, particularly if they appear on the critical path. If work is broken into smaller pieces, some portions of it might be able to start earlier or in parallel with other portions or might be reassigned to other available resources, saving time and possibly moving the activity off the critical path. In particular, summary activities should never be on the critical path. As described in Best Practice 2, linking summary activities obfuscates the logic of the schedule. Tracing logic through summary links does not impart to management the sequence in which lower-level activities should be carried out. If a summary activity becomes critical,

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there is no way to determine which subactivities are critical and which are not.

Predetermined Critical Activities

Finally, because all activities can become critical under some circumstances, intermediate and summary-level schedules should derive their critical paths from detailed schedules while recognizing that this will not be as informative as the full critical path. For example, separate summary schedules should not be created by selectively choosing which lower-level milestones and detail activities management has determined are important to monitor. Activities may be important in terms of cost or scope, but there is little guarantee that hand-picked activities determine the finish milestone date as the project progresses. By only reporting on or monitoring the progress of favorite activities, management risks losing sight of previously unimportant activities that may now be driving the project's finish date (see case study 11).

Case Study 11: Predetermined Critical Activities, from *Immigration Benefits,* GAO-12-66

The U.S. Citizenship and Immigration Services (USCIS) Transformation Program schedule consisted of 18 individual project schedules. To provide an alternative to an IMS and to ease reporting to the Acquisition Review Board and other senior officials, the Transformation Program Office (TPO) developed a high-level tracking tool summarizing dates and activities for the first release of the program based on individual schedules such as the Office of Information Technology and solutions architect schedule, which TPO did not directly manage. TPO used this tool to ensure the coordination and alignment of activities by collaborating with staff responsible for managing individual schedules.

However, this tracking tool was not an IMS because it did not integrate all activities necessary to meet the milestones for Release A. Rather, it was a selection of key activities drawn from the individual schedules that USCIS components and the solutions architect maintained. Moreover, the Transformation Program Manager expressed concern in a May 2011 program management review that the information reported in the high-level tracking tool was not being reported in the individual schedules. In addition, this tracking tool was not an IMS because it did not show activities over the life of the program. That is, it had no dates or activities for the four other releases' set of work activities or how long they would take and how they were related to one another.

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As a result, program officials would have difficulty predicting, with any degree of confidence, how long completing all five releases of the Transformation Program would take. Program officials would also have difficulty managing and measuring progress in executing the work needed to deliver the program, thus increasing the risk of cost, schedule, and performance shortfalls. Last, USCIS would be hindered in accurately communicating the status of Transformation Program efforts to employees, the Congress, and the public.

In addition, neither of the two underlying schedules that GAO assessed had a valid critical path. The USCIS Office of Information Technology schedule had missing or dangling logic on over 61 percent of its remaining activities. The solutions architect's schedule was missing logic on 40 percent of its remaining activities and contained excessive constraints, lags, and dangling logic.

GAO, *Immigration Benefits: Consistent Adherence to DHS's Acquisition Policy Could Help Improve Transformation Program Outcomes,* GAO-12-66 (Washington, D.C.: November 22, 2011).

Resource Leveling

The critical path method of scheduling assumes unlimited resources to accomplish the project. This is true even when the schedule is resource loaded because the critical path does not take into account resource overallocation. That is, a worker can be assigned to any number of parallel activities, regardless of workload. As discussed in Best Practice 3, resource leveling adjusts the scheduled times of activities or work assignments of resources to account for the availability of resources and to improve schedule accuracy and credibility. Resource leveling can be relatively simple as in reassigning work from overallocated resources to underallocated resources or delaying activities until resources are available.

Leveling resources allows management to identify critical resources—those that will delay the project finish date if they are unavailable for specific activities. If resource allocation is an issue that must be addressed in the schedule, the project end date will be determined not solely through network logic but also by considering resource availability. The sequence of activities that drive the project finish date, based on both network logic and resource availability, is called the resource critical path or the resource constrained critical path or critical chain. Although the resource critical path is complex and not easily derived by even the most common schedule software, it represents the most realistic model of activities and resources that determine the minimum possible duration of the project. Once critical resources are determined, management can

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attempt to facilitate its work by, for example, hiring additional help, providing an uninterrupted work environment, or negotiating vacation time so that critical work is not delayed. If management focuses solely on critical activities without taking into account critical resources, it risks ignoring or overworking the program's most valuable assets or jeopardizing the project's timely completion.

Critical Path Management

Without clear insight into a critical path, management cannot determine which slipped activities will be detrimental to key project milestones and the program finish date. More complex schedules will require additional analysis by tracing critical resources. Float within the schedule can be used to mitigate critical activities by reallocating resources from activities that can safely slip to activities that must be completed on time. Until the schedule can produce a credible critical path and a credible longest path, management will not be able to provide reliable timeline estimates or identify problems or changes or their effects. In addition, management will not be able to reliably plan and schedule the detailed work activities.

As stated earlier, the critical path and longest path must be reevaluated after each status update because the sequence of activities that make up the paths will change as activities are delayed, finish early, occur out of planned sequence, or the like. Additionally, activity duration updates and changes to logic may alter the paths. After each status update, the critical path and the longest path should be compared to the previous period's paths, and responsible resources should be alerted if previously noncritical and nondriving activities are now critical or driving. Likewise, resources that had been assigned to previously critical activities may now need to be reassigned to other critical activities. The critical and longest paths should make intuitive sense to subject matter experts. That is, the sequence, logic, and duration of critical activities should appear to be rational and consistent with reviewers' experience.

Depending on the overall duration of the project, management may benefit by monitoring near-critical activities as well. For example, in addition to monitoring critical path activities, management may wish to monitor activities with 5 days or less total float. Monitoring near-critical

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activities alerts management of potential critical activities and facilitates proper resource allocation before activities become critical.[18]

Conducting a schedule risk analysis (Best Practice 8) may reveal that, with risks considered, the path most likely to delay the project is not the critical path or the longest path in the static CPM schedule. The risk analysis may identify a different path or paths that are "risk critical." Risk mitigation should focus on those risk-critical paths for best effect.

Best Practices Checklist: Confirming That the Critical Path Is Valid

- The schedule's critical path is valid. That is, the critical path or longest path in the presence of late-date constraints
  - does not include LOE activities, summary activities, or other unusually long activities;
  - is a continuous path from the status date to the major completion milestones;
  - does not include constraints so that other activities are unimportant in driving the milestone date;
  - is not driven in any way by lags or leads;
  - is derived in summary schedules by vertical integration of lower-level detailed schedules, not preselected activities that management has presupposed are important.
- If backward-pass date constraints are present on activities other than the finish milestone, both the critical path and the longest path have been identified. With a number of constraints, activities with zero or negative total float may outnumber activities that are actually driving the key project completion milestone.
- The critical path, or longest path in the presence of late-date constraints, is used as a tool for managing the program. That is, management
  - has vetted and justified the current critical path as calculated by the software;
  - uses the critical path to focus on activities that will be detrimental to the key project milestones and deliveries if they slip;
  - examines and mitigates risk in activities on the critical path that can potentially delay key program deliveries and milestones;

[18]Unfortunately, no easy method of calculating the "near longest path" in complex schedules would alert management and schedulers to activities near the path of longest duration.

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- has reviewed and analyzed near-critical paths because these activities are likely to overtake the existing critical path and drive the schedule;
- recognizes not only activities with the lowest float but also activities that are truly driving the finish date of key milestones;
- evaluates the critical path before the schedule is baselined and after every status update to ensure that it is valid.

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Best Practice 7: Ensuring Reasonable Total Float

Best Practice 7: The schedule should identify reasonable float (or slack)—the amount of time by which a predecessor activity can slip before the delay affects the program's estimated finish date—so that the schedule's flexibility can be determined. Large total float on an activity or path indicates that the activity or path can be delayed without jeopardizing the finish date. The length of delay that can be accommodated without the finish date's slipping depends on a variety of factors, including the number of date constraints within the schedule and the amount of uncertainty in the duration estimates, but the activity's total float provides a reasonable estimate of this value. As a general rule, activities along the critical path have the least float.

Management should be aware of schedule float. Activities with the lowest float values constitute the highest risk to schedule completion or interim milestones. In general, if zero-float activities or milestones are not finished when scheduled, they will delay the project by time equal to their delayed finish—unless successor activities on the critical path can be completed in less time than originally planned. An activity's delay causes total float to decrease, thus increasing the risk of not completing the project as scheduled.

Incomplete, missing, or incorrect logic; unrealistic activity durations; or unstatused work will distort the value of total float so that it does not accurately represent the schedule's flexibility. In addition, total float may not be a completely accurate measure of flexibility if the schedule has late-date constraints or deadlines such that low or even negative float values for activities do not drive the finish milestone. Thus, it is imperative that project managers for both the acquirer and the contractor proactively manage float as activities are completed. Doing so will ensure that the project schedule accurately depicts the project's flexibility and will enable management to make appropriate decisions on reallocating resources or resequencing work before the project gets into trouble.

Definitions of Total Float and Free Float

Float, or slack, is the amount of time an activity can be delayed before the dates of its successor activities or the program's finish milestone are affected.[19] The two types of float most commonly monitored are total float and free float.[20]

Total Float

Total float, the amount of time an activity can be delayed or extended before delay affects the program's finish date, can be positive, negative, or zero. If positive, it indicates the amount of time that an activity can be

[19]Specifically, float is calculated from an activity's early start date and is the amount of time the activity can be delayed before delaying the early start of its successor or the project finish date.

[20]A schedule network may also mathematically calculate *independent* float and *interfering* float. Independent float is the amount of time the activity can be delayed without delaying successor activities or restricting the scheduling of preceding activities. Interfering float is the difference between an activity's total float and free float.

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delayed without delaying the program's finish date.[21] Negative total float indicates the amount of time that must be recovered so as not to delay the program finish date beyond the constrained date. Negative total float arises when an activity's completion date is constrained—that is, when the constraint date is earlier than the calculated late finish of an activity. In essence, the constraint states that an activity must finish before the date the activity may finish as calculated by network logic. Negative float can also occur when activities are performed in a sequence that differs from the logic dictated in the network. Out-of-sequence logic is discussed in detail in Best Practice 9. Zero total float means that any amount of activity delay will delay the program finish date by an equal amount. An activity with negative or zero total float is considered critical.

Free Float

Free float is the portion of an activity's total float that is available before the activity's delay affects its immediate successor. Depending on the sequence of events in the network, an activity with total float may or may not have free float. For example, an activity may be able to slip 2 days without affecting the finish date (2 days of total float), but its delay will cause a 2-day slip in the start date of its immediate successor activity (zero free float).

Total float and free float are therefore indicators of a schedule's flexibility. Some activities in the schedule network will be able to slip without affecting their immediate successor, and some may affect their immediate successor but not the program finish date. This knowledge allows management to reassign resources from activities that can slip to activities that cannot slip. Knowing the amount of time an activity can or cannot be delayed is essential to successful resource allocation and to completing the program on time.

Nonworking periods are not float. Nonworking periods are defined through resource calendars and dictate the availability of resources to work, not the flexibility of an activity's start or finish dates. In addition, float should not be treated as schedule contingency. Because float is shared along a sequence of activities, it is available for use by any activity along

[21]Typically, total float is calculated by the scheduling software to the last activity in the schedule file, but other activities or interim milestones may be monitored for total float, using constraints on key interim milestones. With these constraints, using total float to identify the critical path to the finish milestone is a flawed method.

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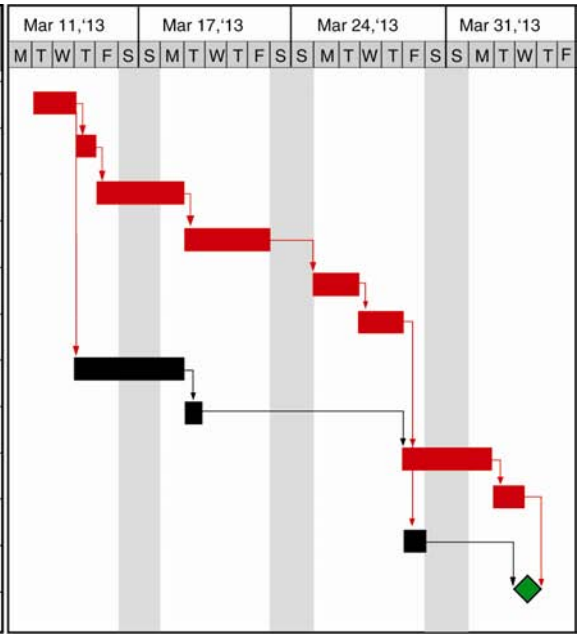
that sequence. As described in Best Practice 8, schedule contingency should be applied to specific activities according to prioritized risks.

Calculating Float

Activities on the same network path share total float. Figure 31 shows a portion of the house construction project's critical path through framing. The critical path (in red) spans activities from "set steel columns and beams" through the "framing complete" milestone. Three activities have total float available: "exterior backfill basement walls," "rough grade property," and "rough-in framing inspection."

Figure 31: Total Float and Free Float

Activity name	Early start	Late start	Free float (in days)	Total float (in days)
Install first floor joists and decking	3-12-13	3-12-13	0	0
Install waterproofing on exterior basement walls	3-14-13	3-14-13	0	0
Finish excavate and pour basement floor	3-15-13	3-15-13	0	0
Frame first floor walls	3-19-13	3-19-13	0	0
Install roof trusses	3-25-13	3-25-13	0	0
Install roof decking	3-27-13	3-27-13	0	0
Exterior backfill basement walls	3-14-13	3-25-13	0	7
Rough grade property	3-19-13	3-28-13	7	7
Form and pour driveway	3-29-13	3-29-13	0	0
Finish excavate and pour garage floor	4-2-13	4-2-13	0	0
Rough-in framing inspection	3-29-13	4-2-13	2	2
Framing complete	4-2-13	4-3-13	0	0



Source: GAO.

While both "exterior backfill basement walls" and "rough grade property" have 7 days of total float available, only "rough grade property" has 7 days of free float available. Any delay backfilling basement walls will delay the rough grading of the property by an equal amount. However, rough grading the property may be delayed up to 7 days without affecting any successor activity.

Note that leveling overallocated resources on the "rough grade property" activity is much easier than on "exterior backfill basement walls" because of the former activity's available free float. Delaying rough grading by 2

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days affects the resources assigned to that activity, but it has no effect on any subsequent activity in the network. But delaying the backfill activity affects also the grading activity and resource assignments for both activities. As shown here, however, leveling resources will always consume float along a path of activities.

Common Barriers to Valid Float

Unreasonable amounts of total float usually result from missing or incomplete logic rather than acceptable periods of potential delay. Therefore, any activities that appear to have a great amount of float should first be examined for missing or incomplete logic. Because total float is calculated from activities' early and late dates, it is directly related to the logical sequencing of events—just like the validity of the resulting critical path. Missing activities, missing or convoluted logic, and date constraints prevent the valid calculation of total float, potentially making an activity appear as though it can slip when it actually cannot. The reasonableness of total float depends on capturing all activities (Best Practice 1) and properly sequencing activities (Best Practice 2). It also depends on realistic resource assignments (Best Practice 3) and accurate status updates (Best Practice 9). Case study 12 shows how unreasonable float values can arise from improperly sequenced activities.

Case Study 12: Unreasonable Float from the Sequencing of Activities, from *FAA Acquisitions,* GAO-12-223

GAO's analysis of FAA's Collaborative Air Traffic Management Technologies system IMS found unreasonable amounts of total float throughout the schedule. For example, 325 (68 percent) of the 481 remaining activities had float values greater than 1,000 days. These unreasonable float values were caused mostly by activities being tied to the project finish milestone, which was constrained to start no earlier than July 1, 2016. Interim milestones that were scheduled to finish earlier than July 1, 2016—such as those marking the end of task orders—were tied to the project finish milestone as predecessors and were therefore showing enormous amounts of float that did not reflect actual flexibility in the schedule. The majority of high-float activities were level of effort activities, many of which were extended to the end of these interim milestones and thus associated with unreasonable amounts of float as well. Several activities had more than 1,000 days of float, including "test and deploy," which showed a total float value of 1,280 days. This excessive float meant that delays in the activities would have no effect on the finish date of the Release 5 end milestone.

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GAO, *FAA's Acquisitions: Management Challenges Associated with Program Costs and Schedules Could Hinder NextGen,* GAO-12-223 (Washington, D.C.: February 16, 2012).

Scheduling software automatically calculates total and free float for activities, which are then used to identify critical activities. However, these values of float must be examined for reasonableness. Unreasonable amounts of float might be negative, positive, or zero float. That is, a network that displays large negative values of total float, such as –300 days for some activities, most likely indicates either missing logic or an unrealistic sequencing of activities. For example, dangling logic can create unrealistic amounts of free float. Because float is shared along activity paths, finding and addressing incomplete logic that causes large float values may solve the float problem for many activities on the path. Likewise, a complex schedule the majority of whose remaining activities are critical is not a realistic plan and should be assessed for reasonable logic, the practicality of resource assignments, or the reasonableness of the project's duration.

Reasonableness of Float

Given that float is directly related to the logical sequencing of activities and indicates schedule flexibility, management and auditors will question what constitutes a reasonable amount of float for a particular schedule. Float differs among activities, given their logical sequence in the network and the overall program duration. Therefore, management should not adhere to a target float value (for example, maximum 2 working periods) or specific float measure (for example, 10 percent of project duration). Large amounts of float may be justified, given the activity's place in the flow of work. For example, landscaping or paving in a construction project may slip many more months than pipefitting. Likewise, nonessential activities in a 2-year program may have far more float available than the same activities in a 6-month project.[22] Case study 13 shows unreasonable float in a schedule.

[22]Total float is also tied to the overall confidence level of a schedule, assuming that a schedule risk analysis has been performed. The more optimistic a schedule may be (less confidence in meeting the completion date), the lower the available float is; the more pessimistic a schedule (more confidence in meeting the completion date), the higher the available float.

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Case Study 13: Reasonable Float, from *Nuclear Waste,* GAO-10-816

GAO initially assessed DOE's Savannah River Salt Waste Processing Facility's construction schedule in March 2010, finding that the schedule had 272 activities with more than 500 working days of float. In addition, two construction activities involving the fabrication of piping—usually critical in construction projects—had more than 1,000 working days of float because neither activity was linked to a successor. After discussion with DOE and contractor officials, DOE made changes to the schedule for the May 2010 assessment. But the problem became worse, when 433 activities proved to have more than 500 days of float—an increase of 59 percent between March and May. In fact, 22 of these activities had more than 1,250 days of float, which was not reasonable. The department was therefore unable to realistically determine how much an activity could slip before the end date would be affected. In this case, apparently activities could slip by up to 3 years and not affect the overall end date.

GAO, *Nuclear Waste: Actions Needed to Address Persistent Concerns with Efforts to Close Underground Radioactive Waste Tanks at DOE's Savannah River Site,* GAO-10-816 (Washington, D.C.: September 14, 2010).

In general, total float should be as accurate as possible and should be evaluated relative to the program's projected finish date. Remaining activities in the schedule should be sorted by total float, and those values should be assessed for reasonableness. Management should determine whether it makes sense logically that any activity with a relatively high amount of float can actually slip that far without affecting the project's finish date. For instance, management should ask, is it reasonable that an activity with 55 days of total float can actually slip 55 working days before the program's finish date is affected? Is the manager of that particular activity aware of this float? A float value of 55 days may make sense for a program that has 4 years of future planning packages, but a 55-day delay would probably be considered implausible in a 6-month project. Total float values that appear to be excessive should be documented to show that the project team, having already performed an analysis, has agreed that the logic and float for this activity is consistent with the plan. If too little float is built into the schedule, no recovery from inevitable delay may prevent the program's completion date from slipping.

All activities with negative float should be questioned. Negative float stems from constraining one or more activities or milestones in the network. The constraint should be examined and justified, and the resulting negative float should be evaluated for reasonableness.

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Management should be aware of activities that are behind schedule with respect to the constrained activity. If the delay is deemed significant, management should develop a plan to examine options for recovering from the schedule slip.

Float Management

Total and free float calculations are fundamental products of CPM scheduling. Network logic, float, durations, and criticality of activities are interrelated. That is, the logical sequence of activities and resource assignments within a network dictate the amount of available float, and the amount of available float defines the criticality of an activity to a constrained milestone or to the final milestone, whether constrained or not. Therefore, management cannot correctly monitor the critical path without also monitoring float. Incorrect float estimates may result in an invalid critical path and an inaccurate assessment of project completion dates. In addition, inaccurate values for total float result in a false depiction of the project's true status, which could lead to decisions that jeopardize the project.

Management must understand the amount of time an activity can or cannot be delayed if it is to successfully allocate resources and manage the resequencing of work. Accurate values of total float can be used to identify activities that could be permitted to slip and resources to reallocate to activities that require more resources if the project is to be completed on time. This knowledge helps in reallocating resources optimally and in identifying the activity sequences that should be managed most closely. However, management must also balance the use of float with the fact that total float is shared along a path of activities. Allowing an activity to consume total float prevents successive activities from being able to slip and expends the schedule's flexibility rather than conserving it for future risks.

Free float is particularly important in resource leveling because leveling generally targets activities with free float first. That is, delaying an activity within its available free float will not affect its successor activity or the project's completion date. Delaying an activity that has total float but no free float does not affect the project's completion date but does disturb successor activity dates that rely on the start or finish of the delayed activity. This, in turn, may disrupt resource availability for assignments along the entire path of successor activities.

Once critical path float has been exhausted, the program is on a day-for-day schedule slip. Float on the critical path should be commensurate with

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program risk, urgency, technological maturity, complexity, and funding profile. Periodic reports should routinely report the amount of float consumed in a period and remaining on the critical and near-critical paths. A portent of things to come can be seen in the consumption of free float. As a program schedule becomes less flexible, the probability of having to consume near-critical path and critical path float is increased.

Best Practices Checklist: Ensuring Reasonable Total Float

- The total float values calculated by the scheduling software are reasonable and accurately reflect true schedule flexibility.
- The project really has the amount of schedule flexibility indicated by the levels of float.
- Remaining activities in the schedule are sorted by total float and assessed for reasonableness. Any activities that appear to have a great deal of float are examined for missing or incomplete logic.
- Total float values that appear to be excessive are documented to show that the project team has performed the assessment and agreed that the logic and float are consistent with the plan.
- Total float is calculated to the main deliveries and milestones as well as to the project completion.
- Total and free float inform management as to which activities can be reassigned resources in order to mitigate slips in other activities.
- Management balances the use of float with the fact that total float is shared along a path of activities.
- Periodic reports routinely show the amount of float consumed in a period and remaining on the critical and near-critical paths.
- Date constraints causing negative float have been justified. If delay is significant, plans to recover the implied schedule slip have been evaluated and implemented, if so decided.

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Best Practice 8: Conducting a Schedule Risk Analysis

Best Practice 8: A schedule risk analysis uses a good critical path method (CPM) schedule and data about project schedule risks and opportunities as well as statistical simulation to predict the level of confidence in meeting a program's completion date, determine the time contingency needed for a level of confidence, and identify high-priority risks and opportunities. As a result, the baseline schedule should include a buffer or reserve of extra time.

The results of risk analysis are best viewed as inputs to project management rather than as forecasts of how the project will be completed. The results indicate when the project is likely to finish without the project team's taking additional risk mitigation steps. The high-priority risks can be identified and used to guide further risk mitigation actions. A schedule risk analysis may prove that a given schedule has more risk than is acceptable. In this case, a review of the activities, dependencies, and network might help derive a less risky sequence of work. However, the initial estimates of efforts and durations should not be changed without sufficient justification.

The Definition of Schedule Risk Analysis

A schedule risk analysis uses statistical techniques to predict a level of confidence in meeting a program's completion date. This analysis focuses on key risks and how they affect the schedule's activities.[23] The analysis does not focus solely on the critical path because, with risk considered, any activity may potentially affect the program's completion date. A schedule risk analysis requires the collection of program risk data such as

- risks that may jeopardize (threats) or enhance (opportunities) schedule success, usually found in the risk register prepared before the risk analysis is conducted;[24]
- probability distributions of risk impact if it occurs, usually specified by a three-point estimate of activity durations (optimistic, most likely, and pessimistic) or multiplicative factors if the risk is to be applied to several activities;
    - the probability of a risk's occurring;
    - the probability that a branch of activities might occur (for example, a test failure could lead to several recovery activities); and
    - correlations between uncertain activity durations, whether specified directly or calculated.

[23]For more information on the difference between uncertainty and risk, see Chapter 14 in the GAO *Cost Estimating and Assessment Guide*, GAO-09-3SP.

[24]A risk register formally documents a project's identified risks, including likelihoods, consequences, mitigation plans, and current status.

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Risk data should be derived from quantitative risk assessment and should not be based on arbitrary percentages or factors. A risk assessment is a part of the program's overall risk management process in which risks are identified and analyzed and the program's risk exposure is determined. As risks are identified, risk-handling plans are developed and incorporated into the program's cost estimate and schedule as necessary.[25]

Schedule risk analysis relies on statistical simulation to randomly vary the following:

- activity durations according to their probability distributions;
- risks and opportunities according to their probability of occurring and the distribution of their impact on affected activities if they were to occur; and
- the existence of a risk or probabilistic branch.

The objective of the simulation is to develop a probability distribution of possible completion dates that reflect the program plan (represented by the schedule) and its quantified risks and opportunities. From the cumulative probability distribution, the organization can match a date to its degree of risk tolerance. For instance, an organization might want to adopt a program completion date that provides a 70 percent probability that it will finish on or before that date, leaving a 30 percent probability that it will overrun, given the schedule and the risks as they are known and calibrated. The organization can thus adopt a plan consistent with its preferred level of confidence in the overall integrated schedule. This analysis can give valuable insight into what-if drills and can quantify the effect of program changes (see case study 14).

Case Study 14: Conducting a Schedule Risk Analysis, from *Transportation Worker Identification Credential,* GAO-10-43

Transportation Worker Identification Credential (TWIC) program officials did not perform a schedule risk analysis (SRA) for the pilot program IMS because they did not believe it necessary. For the TWIC pilot, an SRA could have enabled the program to model "what if" scenarios as to when and whether locations such as Long Beach would complete their preliminary work and the effects that schedule

[25]For more information on formal risk assessments and their relation to cost, schedule, and EVM, see GAO-09-3SP.

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> changes, if any, might have had on meeting the pilot reporting goal. Also, because the schedule was not shared with pilot participants, no SRA helped facilitate detailed discussions between the TWIC program office at TSA and the individual pilot locations regarding task durations and expected progress. This would have been especially relevant for the TWIC pilot given that the schedule did not clearly articulate all the activities that had to be completed to carry out the pilot or changes that may have resulted from the availability of funding. For example, according to TSA officials and one pilot participant, such changes included delays in the approval by the Federal Emergency Management Agency of pilot participants' award contracts to allow the grantees to expend grant funds. In programs that lack a schedule risk analysis, it is not possible to reliably determine a level of confidence for meeting the completion date.
>
> GAO, *DOD Transportation Worker Identification Credential: Progress Made in Enrolling Workers and Activating Credentials but Evaluation Plan Needed to Help Inform the Implementation of Card Readers,* GAO-10-43 (Washington, D.C.: November 18, 2009).

When a schedule risk analysis is developed, probability distributions for each activity's duration have to be established. Further, risk and opportunities in all activities must be evaluated and included in the analysis. The risk analysis should not be focused solely on the deterministic critical path. Because the durations of activities are uncertain, the true critical path is uncertain. Any off-critical path activity might become critical if a risk were to occur. Typically, three-point estimates—that is, best, most likely, and worst case estimates—are used to develop the probability distributions for the durations of activities. Alternatively, the risk driver approach specifies the probability that a risk will occur, its impact in multiplicative terms on the durations of activities that it affects if it occurs, and the identity of those activities. After the risk information is developed, the statistical simulation is run and the resulting cumulative distribution curve, the S curve, displays the probability associated with the range of program completion dates.

If the analysis is to be credible, the program must have a good schedule network that clearly identifies the work that is to be done and the relationships between detailed activities. The schedule should be based on a minimum number of justified date constraints. The risk analysis should also identify the activities during the simulation that most often ended up on the critical path, so that near risk-critical path activities can also be identified and closely monitored. It is important to represent all work in the schedule, because any activity can become critical under

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some circumstances. Complete schedule logic that addresses the logical relationships between predecessor and successor activities is also important. The analyst needs to be confident that the schedule will automatically calculate the correct dates and critical paths when the activity durations change, as they do thousands of times during a simulation. If time or resources are insufficient to simulate the full program, or if the level of detail is unclear because of rolling wave planning, the simulation can be performed on a summary version of the schedule.

The Purpose of a Schedule Risk Analysis

One of the most important reasons for performing a schedule risk analysis is that the overall program schedule duration may well be greater than the sum of the path durations for lower-level activities. This is so partly because of schedule uncertainty and schedule structure.

Schedule uncertainty can cause activities to shorten (an opportunity) or lengthen (a threat). For instance, if a conservative assumption about labor productivity was used in calculating the duration of an activity and during the simulation a better labor productivity is possible, then the activity will shorten, at least for that iteration. However, most program schedule risk phenomena exhibit more probability of overrunning than underrunning.

A schedule's structure has many parallel paths connected at a merge or join point that can cause the schedule to lengthen. Merge points include program reviews (preliminary design review, critical design review, and the like) or the beginning of an integration and test phase. The timing of these merge points is determined by the latest merging path. Thus, if a required element is delayed, the merge event will also be delayed. Because any merging path can be risky, any merging path can determine the timing of the merge event. This added risk at merge points is called the "merge bias." Figure 32 gives an example of the schedule structure that illustrates the network or pure-logic diagram of a simple schedule with a merge point at integration and test.

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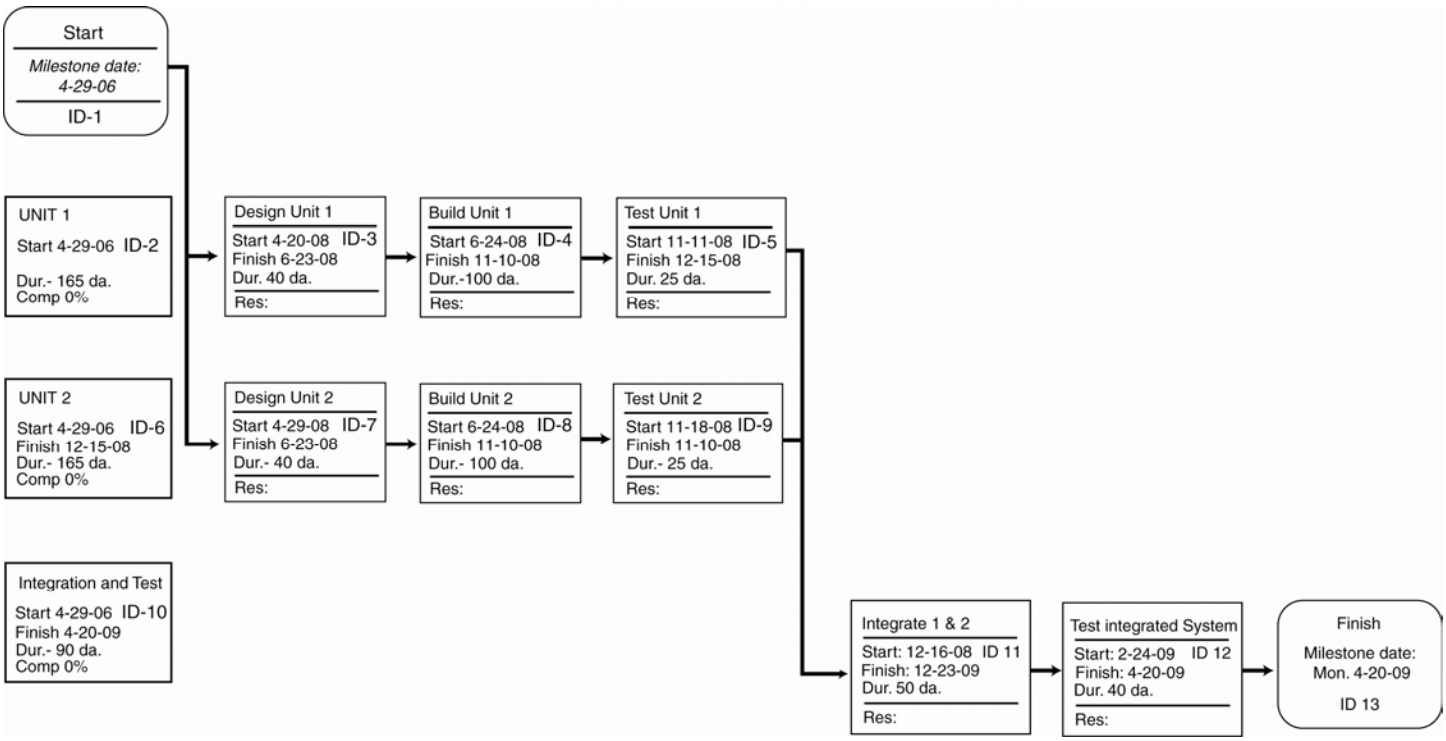
Figure 32: Network Diagram of a Simple Schedule



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Because each activity has an uncertain duration, it stands to reason that the entire duration of the overall program schedule will also be uncertain. Therefore, unless a statistical simulation is run, calculating the completion date based on schedule logic and the most likely duration distributions will tend to underestimate the overall program critical path duration.

Schedule underestimation is more pronounced when the schedule durations or logic have optimistic bias—for instance, when the customer or management has specified an unreasonably short duration or early completion date and when there are several points where parallel paths merge. Case study 15 highlights the potential impacts of converging activities on scheduled activities.

Case Study 15: Converging Paths and Schedule Risk Analysis, from *Coast Guard,* GAO-11-743

The Coast Guard program office and Northrop Grumman officials said that schedule risk analysis (SRA) was not required for the National

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Security Cutter 3 (NSC 3) production contract and therefore was not performed.

In the December 2010 program management review, only one risk was identified: "test or installation phase failure." Given that the schedule in February 2011 had 3,920 remaining activities, one identified risk seemed improbable. For example, Northrop Grumman officials said that the critical end milestone they were most concerned about was "preliminary delivery of NSC." However, this milestone was not on the risk list. The critical milestone had 5 days of negative float and 57 converging predecessors. That is, the task was already 5 days behind schedule on the status date, and—compounding the risk—had multiple converging activity paths, which decreased the probability of meeting the planned milestone date. The chance that the milestone will be accomplished on time decreases with every additional path leading up to the milestone. The more parallel paths existing in the schedule, the greater is the schedule risk. A Monte Carlo SRA simulation could have helped identify the compound effect of parallel paths and could have quantified how much contingency reserve or buffer was needed in the schedule to mitigate the risk.

Agency officials and Northrop Grumman said that a schedule risk analysis would be performed as part of the NSC 4 schedule.

GAO, Coast Guard: Action Needed As Approved Deepwater Program Remains Unachievable, GAO-11-743 (Washington, D.C.: July 28, 2011).

Schedule Risk Analysis with Three-Point Duration Estimates

Because activity durations are uncertain, the probability distribution of the program's total duration must be determined statistically, by combining the individual probability distributions of all paths according to their risks and the logical structure of the schedule. Schedule activity duration uncertainty can be represented several ways, as illustrated by figure 33.

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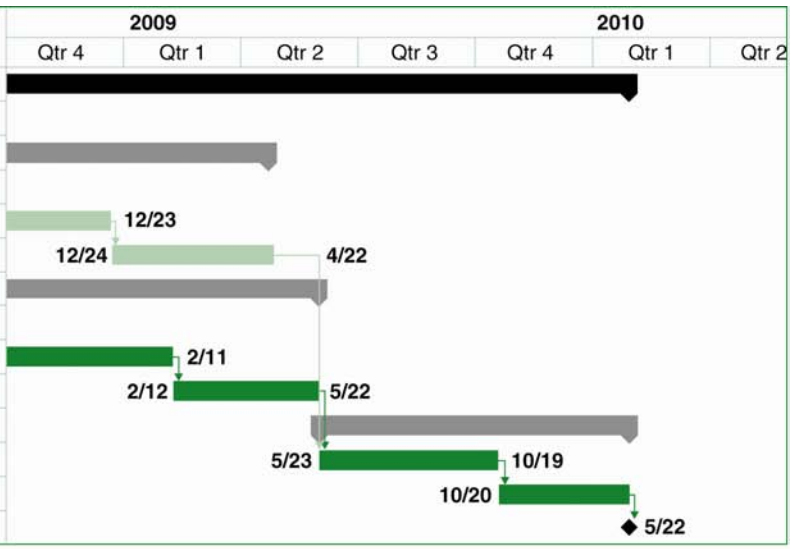
Figure 33: A Project Schedule

ID	Task name	Duration	Start	Finish
0	**Three path project GAO**	**750 d**	**1/9/08**	**1/27/10**
1	Start	0 d	1/9/08	1/9/08
2	**Software**	**470 d**	**1/9/08**	**4/22/09**
3	Software design	100 d	1/9/08	4/17/08
4	Software coding	250 d	4/18/08	12/23/08
5	Software testing	120 d	12/24/08	4/22/09
6	**Hardware**	**500 d**	**1/9/08**	**5/22/09**
7	Hardware design	100 d	1/9/08	4/17/08
8	Hardware fabrication	300 d	4/18/08	2/11/09
9	Hardware test	100 d	2/12/09	5/22/09
10	**Integration H/W and S/W**	**250 d**	**5/23/09**	**1/27/10**
11	Integration	150 d	5/23/09	10/19/09
12	Integrated test	100 d	10/20/09	1/27/10
13	Finish	0 d	1/27/10	1/27/10



Source: Copyright 2007 Hulett and Associates, LLC.

Note: H/W = hardware; S/W = software.

In this example, the project begins on January 9, 2008, and is expected to be completed about 2 years later, on January 27, 2010. Three major efforts involve software, hardware, and integration. According to the schedule logic and durations, hardware fabrication, testing, and the integration of hardware and software drive the critical path.

The first way to capture schedule activity duration uncertainty is to collect various estimates from individuals and, perhaps, from a review of actual program performance. Estimates derived from interviews should be formulated by a consensus of knowledgeable technical experts and coordinated with the same people who manage the program's risk mitigation watch list. Figure 34 shows a traditional approach with a three-point estimate applied directly to the activity durations.

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Figure 34: Estimated Durations for Remaining WBS Areas in the Schedule

ID	Task name	Rept ID	Mn Rdur	ML Rdur	Max Rdur	Rept ID
0	**Three path GAO project**	**2**	**0 d**	**0 d**	**0 d**	**0**
1	Start	0	0 d	0 d	0 d	0
2	**Software**	**0**	**0 d**	**0 d**	**0 d**	**0**
3	Software design	0	85 d	100 d	150 d	2
4	Software coding	0	212.5 d	250 d	375 d	2
5	Software testing	0	90 d	120 d	240 d	2
6	**Hardware**	**0**	**0 d**	**0 d**	**0 d**	**0**
7	Hardware design	0	85 d	100 d	130 d	2
8	Hardware fabrication	0	255 d	300 d	390 d	2
9	Hardware test	0	75 d	100 d	200 d	2
10	**Integration H/W and S/W**	**0**	**0 d**	**0 d**	**0 d**	**0**
11	Integration	0	120 d	150 d	210 d	2
12	Integrated test	0	75 d	100 d	200 d	2
13	Finish	0	0 d	x d	0 d	0

Source: Copyright 2007 Hulett and Associates, LLC.

Note: Rept ID = report identification; Rdur = remaining duration, Mn = minimum, ML = most likely, Max = maximum; H/W = hardware; S/W = software.

The example shows three-point estimates of remaining durations. In an actual program schedule risk analysis, these would be developed from in-depth interviews of people who are knowledgeable in each of the WBS areas of the program. To model the risks in the simulation, the risks are represented here as triangular distributions specified by the three-point estimates of the activity durations. Other distributions besides the triangular are traditionally available as well.[26]

Once the distributions have been established, a statistical simulation (typically a Monte Carlo simulation) uses random numbers to select specific durations from each activity probability distribution and calculates a new critical path and dates, including major milestone and program completion. The Monte Carlo simulation continues this random selection thousands of times, creating a new program duration estimate and critical path each time. The resulting frequency distribution displays the range of program completion dates along with the probabilities that activities will occur on these dates, as seen in figure 35.

[26]For more information on developing probability distributions to model uncertainty, see chapter 14 in the GAO *Cost Estimating and Assessment Guide*, GAO-09-3SP.

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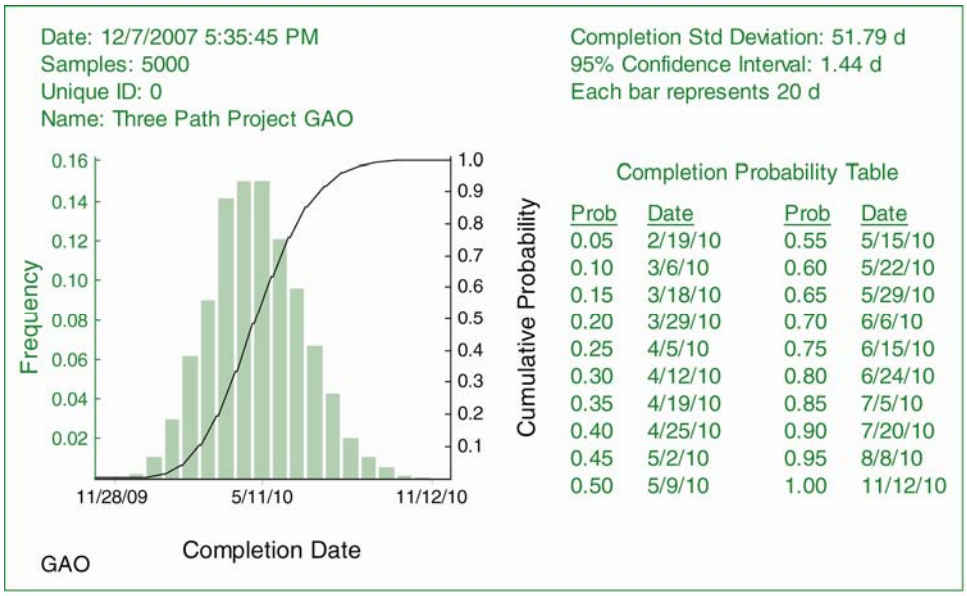
Figure 35: The Cumulative Distribution of Project Schedule, Including Risk



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The figure shows that the most likely completion date is about May 11, 2010, not January 27, 2010, which is the date the deterministic schedule computed. The cumulative distribution also shows that, in this case study, the schedule completion date of January 27, 2010, is less than 5 percent likely to occur, given the schedule and the risk ranges used for the durations.

Schedule Risk Analysis with Risk Drivers

A second way to determine schedule activity duration uncertainty involves analyzing the probability that risks from the risk register may occur and what their effect on schedule activities will be if they do occur. With this approach, a probability distribution of the risk impact—expressed as a multiplicative factor—on the duration of activities in the schedule is estimated and the risks are assigned to specific activities in the schedule. In this way, activity duration risk is estimated indirectly by the root cause risks and their assignment to activities. A risk can be assigned to multiple activities and the durations of some activities can be influenced by multiple risks. This risk driver approach focuses on risks and their contribution to time contingency as well as on risk mitigation. The spacecraft schedule example in figure 36 shows how this approach can be used.

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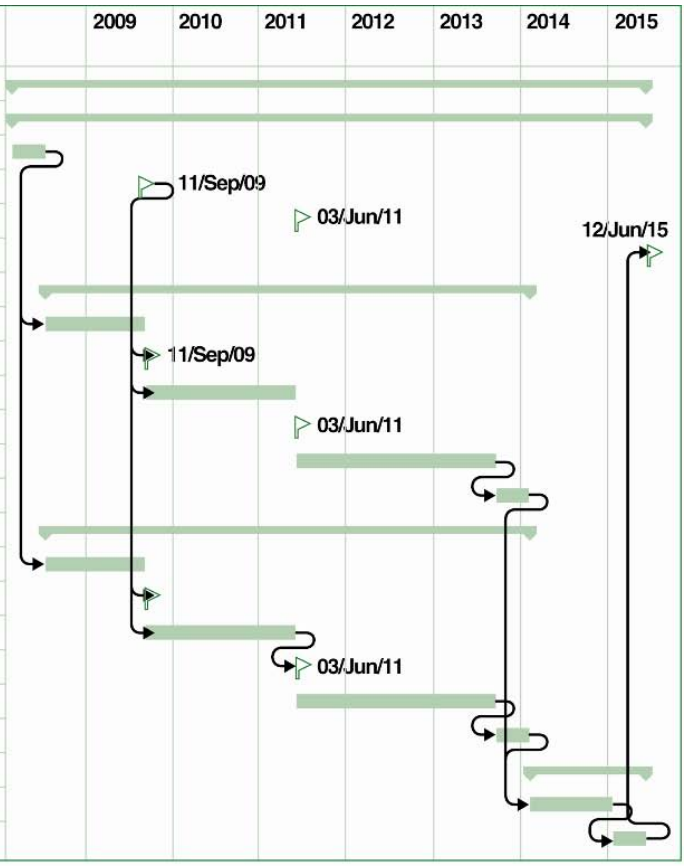
Figure 36: Identified Risks on a Spacecraft Schedule

ID	Description	Rem duration	Start	Finish
SUMMA	Project summary	1900	03/Mar/08	12/Jun/15
00001	Spacecraft project milestones	1900	03/Mar/08	12/Jun/15
00002	Requirements definition spacecraft	100	03/Mar/08	18/Jul/08
00003	PDR spacecraft	0		11/Sep/09
00004	CDR spacecraft	0		03/Jun/11
00005	Ship to launch site	0		12/Jun/15
00006	First stage	1450	21/Jul/08	07/Feb/14
00007	FS preliminary design	300	21/Jul/08	11/Sep/09
00008	FS PDR	0		11/Sep/09
00009	FS final design	450	14/Sep/09	03/Jun/11
00010	FS CDR	0		03/Jun/11
00011	FS fabrication	600	06/Jun/11	20/Sep/13
00012	Test FS engine	100	23/Sep/13	07/Feb/14
00020	Upper stage	1450	21/Jul/08	07/Feb/14
00021	US preliminary design	300	21/Jul/08	11/Sep/09
00022	US PDR	0		11/Sep/09
00023	US Final design	450	14/Sep/09	03/Jun/11
00024	US CDR	0		03/Jun/11
00025	US fabrication	600	06/Jun/11	20/Sep/13
00026	US test	100	23/Sep/13	07/Feb/14
00027	Integration	350	10/Feb/14	12/Jun/15
00028	Integration	250	10/Feb/14	23/Jan/15
00029	Integration testing	100	26/Jan/15	12/Jun/15



Source: Copyright 2007 Hulett and Associates, LLC.

In this example of a spacecraft schedule, the work begins on March 3, 2008, and is expected to finish more than 7 years later, on June 12, 2015. Because of the long time and the risk associated with developing the spacecraft technology, the risk driver method can be used to examine how various risks from the risk register may affect this schedule.

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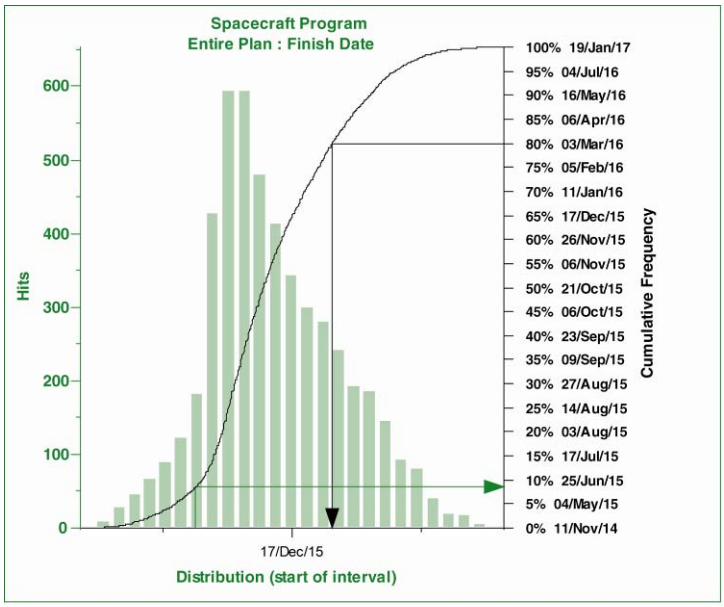
Figure 37: A Risk Register for a Spacecraft Schedule

	Description	Optimistic	Most likely	Pessimistic	Likelihood
1	Requirements have not been decided	95.00%	105.00%	120.00%	30.00%
2	Several alternative designs considered	95.00%	100.00%	115.00%	60.00%
3	New designs not yet proven	96.00%	103.00%	112.00%	40.00%
4	Fabrication requires new materials	96.00%	105.00%	115.00%	50.00%
5	Lost know-how since last full spacecraft	95.00%	100.00%	105.00%	30.00%
6	Funding from congress is problematic	90.00%	105.00%	115.00%	70.00%
7	Schedule for testing is aggressive	100.00%	120.00%	130.00%	100.00%

Source: Copyright 2007 Hulett and Associates, LLC.

In Figure 37, we can quickly determine that the biggest risk in the spacecraft schedule has to do with testing, because the schedule is very aggressive and some tests are always on the critical path. Moreover, a lack of requirements, funding delays, alternative designs, and the fact that some of the designs are unproven are also highly likely to affect the schedule. With the risk driver method, these risks are shown as factors that will be used to multiply the durations of the activities they are assigned to, if they occur in the iteration. Once the risks are assigned to the activities, a simulation is run. The results may be similar to those in figure 38.

Figure 38: Spacecraft Schedule Results from a Monte Carlo Simulation



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In this example, the schedule date of June 12, 2015, is estimated to be 9 percent likely, based on the current plan. If the organization chooses the 80th percentile, the date would be March 3, 2016, representing a 9-month time contingency. Notice that the risks have caused a 14-month spread, a respectable range of uncertainty, between the 5 percent and 95 percent confidence dates. A schedule risk analysis can provide valuable information to senior decision makers, as shown in case study 16.

Case Study 16: Schedule Risk Analysis, from VA Construction, GAO-10-189

GAO performed a schedule risk analysis (SRA) on the construction schedule for Phase IV of the Department of Veterans Affairs' (VA) new Medical Center Complex in Las Vegas, Nevada.

The project executive identified 22 different risks in an exercise preliminary to this analysis. Using these risks as a basis for discussion, GAO interviewed 14 experts familiar with the project, including VA resident engineers, general contractor officials, and architect and engineer consultants. In these interviews, GAO identified 11 additional risks. During data analysis, some risks were consolidated with others and some were eliminated because of too few data. Finally, 20 risks were incorporated into the Monte Carlo simulation. They included 18 risk drivers, 1 schedule duration risk, and 1 overall system commissioning activity that was not included in the baseline schedule.

The schedule duration risk was applied to each activity duration to represent the inherent inaccuracy of scheduling. Of the 6,098 activities in the schedule, GAO assigned risk drivers to 3,193. Some activities had one or two risks assigned, but some had as many as seven.

Beyond applying 20 risks to the schedule, GAO was interested in identifying the marginal effect of each risk. Therefore, GAO identified the risks that had the greatest effect on the schedule, because they should have been targeted first for mitigation. Marginal effect translates directly to potential calendar days saved if the risk is mitigated.

GAO's analysis of the medical center construction schedule concluded that VA should realistically expect VA acceptance between March 1, 2012, and May 17, 2012, the 50th and 80th percentiles. It was determined that the must-finish date of August 29, 2011 was very unlikely. The analysis showed that the probability of achieving VA

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acceptance by October 20, 2011, was less than 1 percent, given the current schedule without risk mitigation.

VA's actual acceptance was December 19, 2011, approximately 4 months later than what had originally been expected. Delays stemmed from issues with steel fabrication and erection, as well as changes to equipment requirements. At the time of GAO's original analysis, December 19, 2011 fell within the 10th to 15th percentile.

GAO, VA Construction: VA is Working to Improve Initial Project Cost Estimates, but Should Analyze Cost and Schedule Risks, GAO-10-189 (Washington, D.C.: December 14, 2009).

Schedule Contingency

A baseline schedule should include a buffer or a reserve of extra time, referred to as schedule contingency, to account risk[27] The contingency represents a gap in time between the finish date of the last activity (the planned date) and the finish milestone (the committed date). When schedule contingency is depicted this way, a delay in the finish date of the predecessor activity results in a reduction of the contingency activity's duration. This reduction translates into the consumption of schedule contingency.

Schedule contingency should be calculated by performing a schedule risk analysis and comparing the schedule date with that of the simulation result at a desired level of certainty. For example, an organization may want to adopt an 80 percent chance that its project will finish on time. The amount of contingency necessary would be the difference in time between the 80th percentile date and the date associated with the percentile of the deterministic finish date.

For some projects, the 80th percentile is considered a conservative promise date. Other organizations may focus on another probability, such as the 65th or 55th percentile. However, these percentiles are not as certain as the 80th percentile and may expose the project to overruns if

[27] For our purposes in this guide, contingency represents time reserve held at or above the government program management office for "unknown unknowns" that are outside a contractor's control. In this context, schedule contingency is added to a schedule to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and for which experience implies likely delays. Schedule reserve, in contrast, is for "known unknowns" that are tied to the contract's scope and managed at the contractor level. We recognize that other organizations may define the terms schedule contingency, schedule reserve, schedule buffer, and schedule margin differently.

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they are adopted. Factors such as project type, contract type, and technological maturity will affect each organization's determination of its tolerance level for schedule risk.

Schedule contingency or reserve is held by the project manager but can be allocated to contractors, subcontractors, partners, and others as necessary for their scope of work. When margin needs to be allocated, a formal change process should be followed. Subjecting schedule contingency to the program's change control process ensures that variances can be tracked and monitored and that the use of contingency is transparent and traceable.

Schedule contingency may appear as a single activity just prior to the finish milestone or it may be dispersed throughout the schedule as multiple activities prior to key milestones. For example, it might be appropriate to plan a contingency activity before the start of a key integration activity that depends on several external inputs to ensure readiness to start. In addition, dispersing contingency to specific key milestones may prevent its being consumed prematurely or superfluously. However, in general, apportioning contingency in advance to specific activities is not recommended because the risks that will actually occur and the magnitude of their effects are not known in advance. Contingency should be allocated according to the prioritized risk list. Moreover, contingency that is dispersed throughout the schedule is less visible and may be harder to track and monitor. Contingency reserved to specific activities may also encourage team members to work toward late dates rather than the expected early dates. By aggregating contingency, everyone on the project will be working to protect the schedule contingency as a whole, not simply their own portion. Regardless of whether contingency is captured at the end of the schedule or just before key milestones, representing it as activities will help ensure that the schedule is not hiding potential problems.

Note that contingency is not the same as float. As described in Best Practice 7, float is the amount of time by which an activity can be delayed before it affects the dates of its successor activities or the program finish milestone. Float is directly related to network logic and is calculated from early and late dates of activities. Schedule contingency, in contrast, is determined by a schedule risk analysis that compares the schedule date with that of the simulation result at a desired level of certainty. Moreover, schedule contingency should not be represented as a lag between two activities. Lags are not specifically named in schedules and the associated contingency may become lost within the network logic.

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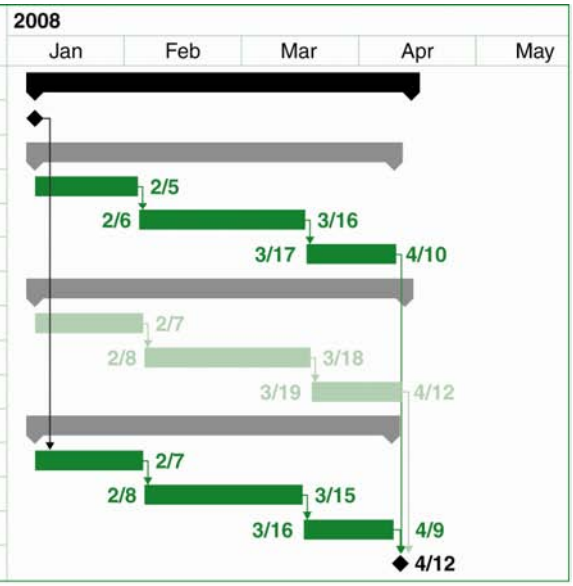
Prioritizing Risks

Regardless of the method used to examine schedule activity duration uncertainty, it is important to identify the risks that contribute most to the program schedule risk. Figure 39 shows one approach to identifying activities that need close examination for effective risk mitigation because they may ultimately determine the duration of the project. It compares a schedule with a well-managed critical path (unit 2) and two other paths that have risk but positive total float. The noncritical path efforts (units 1 and 3) therefore did not attract the program manager's risk management attention.

Figure 39: A Schedule Showing a Critical Path

Task name	Rept ID	Mn Rdur	Mn Rdur	Max Rdur	Curve
Risk criticality project	**2**	**0 d**	**0 d**	**0 d**	**0**
Start	0	0 d	0 d	0 d	0
Unit 1	**0**	**0 d**	**0 d**	**0 d**	**0**
Design unit 1	0	18 d	28 d	43 d	2
Build unit 1	0	35 d	40 d	50 d	2
Test unit 1	0	20 d	25 d	50 d	2
Unit 2	**0**	**0 d**	**0 d**	**0 d**	**0**
Design unit 2	0	25 d	30 d	38 d	2
Build unit 2	0	37 d	40 d	45 d	2
Test unit 2	0	22 d	25 d	35 d	2
Unit 3	**0**	**0 d**	**0 d**	**0 d**	**0**
Design unit 3	0	20 d	30 d	45 d	2
Build unit 3	0	32 d	37 d	47 d	2
Test unit 3	0	20 d	25 d	50 d	2
Finish	0	0 d	0 d	0 d	0



Source: Copyright 2007 Hulett and Associates, LLC.

Note: Rept ID = report identification; Rdur = remaining duration, Mn = minimum, ML = most likely, Max = maximum; H/W = hardware; S/W = software.

The measure of merit, the risk criticality, shows that the risky noncritical paths are more likely to delay the project than the original critical path. Figure 40 shows the results of each unit's probability of landing on the critical path, based on the Monte Carlo simulation.

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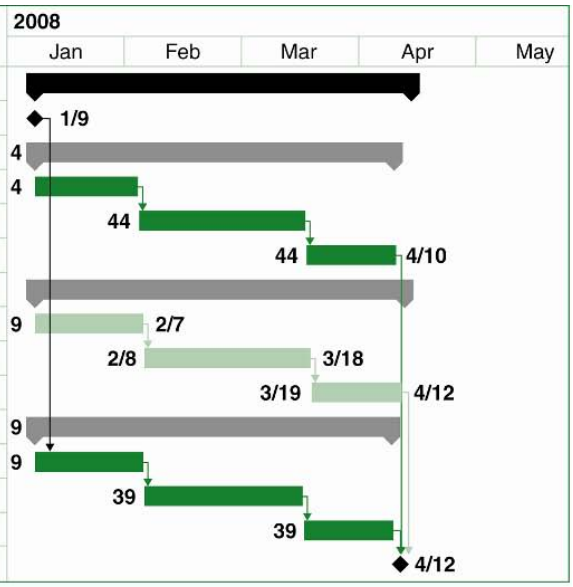
Figure 40: The Results of a Monte Carlo Simulation for a Schedule Showing a Critical Path

ID	Task name	Total slack	Critical	% Critical	Risk Critical
0	**Risk criticality project**	**0 d**	**Yes**	**0**	**No**
1	Start	0 d	Yes	100	No
2	**Unit 1**	**2 d**	**No**	**44**	**Yes**
3	Design unit 1	2 d	No	44	Yes
4	Build unit 1	2 d	No	44	Yes
5	Test unit 1	2 d	No	44	Yes
6	**Unit 2**	**0 d**	**Yes**	**17**	**No**
7	Design unit 2	0 d	Yes	17	No
8	Build unit 2	0 d	Yes	17	No
9	Test unit 2	0 d	Yes	17	No
10	**Unit 3**	**3 d**	**No**	**39**	**Yes**
11	Design unit 3	3 d	No	39	Yes
12	Build unit 3	3 d	No	39	Yes
13	Test unit 3	3 d	No	39	Yes
14	Finish	0 d	Yes	100	No



Source: Copyright 2007 Hulett and Associates, LLC.

After running the simulation, which takes into account the minimum, most likely, and maximum durations, we can see that although unit 2 is on the schedule's deterministic critical path, unit 1 is 44 percent likely to delay the project and unit 3 is 39 percent likely to do the same. In other words, the critical path method "critical path" is the least likely path to delay the project, perhaps because the project manager was successful in mitigating the risks on the CPM critical path.

Other measures of risk importance can be reviewed. For instance, sensitivity measures reflecting the correlation of the activities or the risks with the final schedule duration can be produced by most schedule risk software. Figure 41 is a standard schedule sensitivity index for the spacecraft project discussed earlier.

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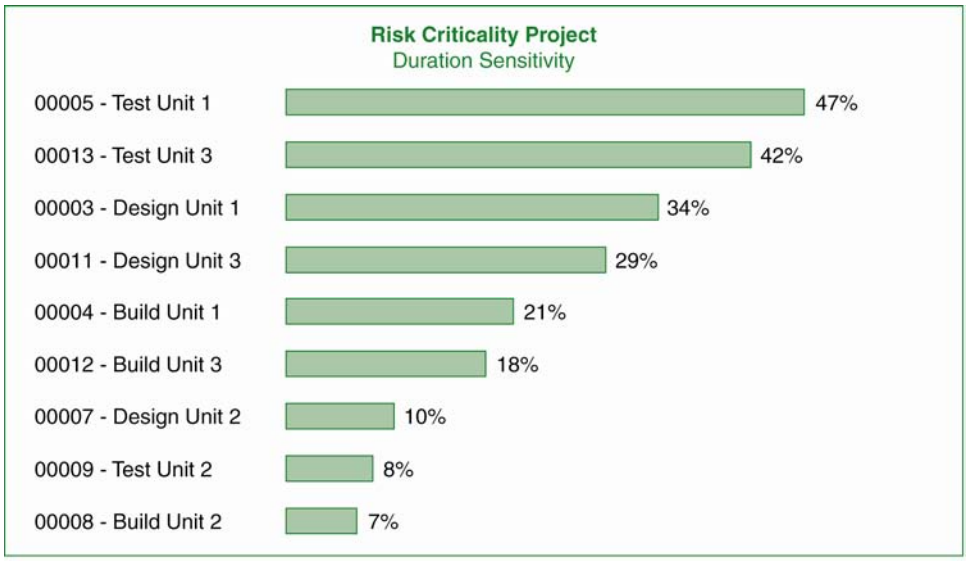
Figure 41: A Sensitivity Index for Spacecraft Schedule



Source: Copyright 2007 Hulett and Associates, LLC.

In this example, the durations of the testing and design activities of units 1 and 3 show the highest correlation with the overall schedule duration more than the design, testing, and building of unit 2, even though unit 2 represents the critical path in the deterministic schedule. Therefore, without taking into account the risk associated with each unit's duration, the program manager would not know that keeping a strong eye on units 1 and 3 would be imperative for keeping the program on schedule.

Probabilistic Branching

In addition to standard schedule risk and sensitivity analysis, typical events in government programs require adding some new activities to the schedule. This is called "probabilistic branching." One common event is the completion of a test of an integrated product (for example, a software program or satellite). The schedule often assumes that tests are successful, whereas experience indicates that tests may fail and that their failure will require the activities of root cause analysis, plan for recovery, execution of recovery, and retest. This is a branch that happens only with some probability. An example is shown in figure 42.

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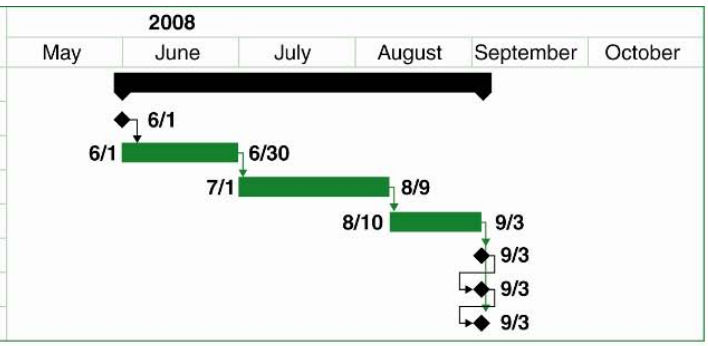
Figure 42: Probabilistic Branching in a Schedule

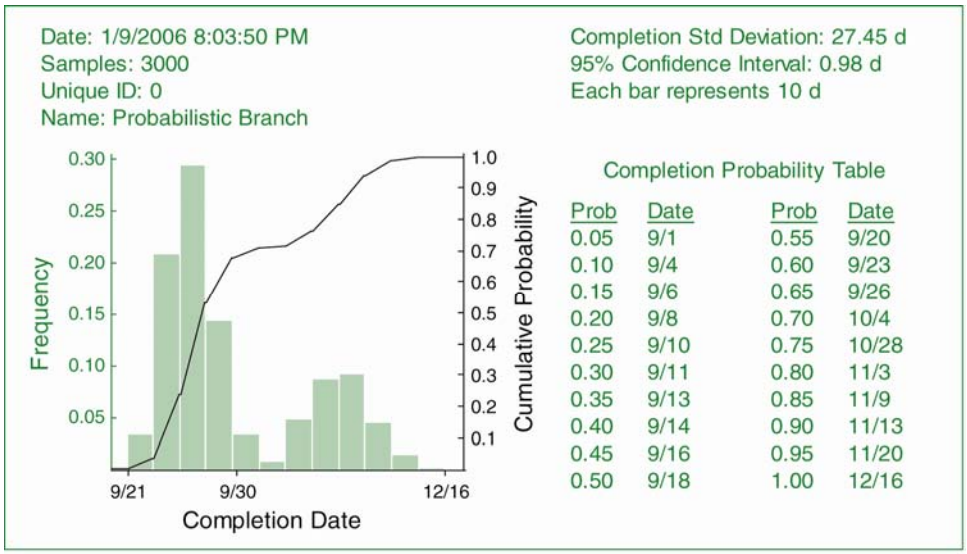
ID	Task name	Duration	Start	Finish	Predecessor
1	Project	95 d	6/1	9/3	
2	Start	0 d	6/1	6/1	
3	Design Unit	30 d	6/1	6/30	2
4	Build Unit	40 d	7/1	8/9	3
5	Test Unit	25 d	8/10	9/3	4
6	FIXIT	0 d	9/3	9/3	5
7	Retest	0 d	9/3	9/3	6
8	Finish	0 d	9/3	9/3	7,5



Source: Copyright 2007 Hulett and Associates, LLC.

If the test unit activity fails, FIXIT and retest occur; otherwise, their duration is 0 days. This is a discontinuous event that leads to the two new activities. If the test is estimated to fail with some probability, such as 30 percent, the resulting probability distribution of dates for the entire project can be depicted as in figure 43.

Figure 43: Probability Distribution Results for Probabilistic Branching



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Notice the bimodal distribution with the test success iterations on the left of figure 43 and the test failure iterations on the right. If the organization

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demanded an 80th percentile schedule, this would be November 3, although if it is satisfied by anything under the 70th percentile, the possibility of failure would not be important.[28]

Correlation

Other capabilities are possible once the schedule is viewed as a probabilistic statement of how the program might unfold. One that is notable is the correlation between activity durations. Positive correlation is when two activity durations are both influenced by the same external force and can be expected to vary in the same direction within their own probability distributions in any consistent scenario. While durations might vary in opposite directions if they are negatively correlated, this is less common than positive correlation in program management. Correlation might be positive and fairly strong if, for instance, the same assumption about the maturity of a technology is made to estimate the duration of design, fabrication, and testing activities. If the technology maturity is not known with certainty, it would be consistent to assume that design, fabrication, and testing activities would all be longer or shorter together. Without specifying correlation between these activity durations in simulation, some iterations or scenarios would have some activities that are thought to be correlated go long and others short in their respective ranges during an iteration. This would be inconsistent with the idea that they all react to the maturity of the same technology.

Specifying correlations between design, fabrication, and testing ensures that each iteration represents a scenario in which their durations are consistently long or short in their ranges, together. Because schedules tend to add durations (given their logical structure), if the durations are long together or short together there is a chance for very long or very short projects. .Correlation affects the low and high values in the simulation results. That means that the high values are even higher with correlation and the low values are even lower, because correlated durations tend to reinforce each other down the schedule paths. If the organization wants to focus on the 80th percentile, correlation matters,

[28]Probabilistic branching is used to model the random choice between two alternatives. An advanced technique known as “conditional processing” is also available in an SRA. With conditional processing, an action is determined by some scheduled event rather than randomness. That is, it is modeled as an “If…then…else” statement rather than a probability of occurrence. For example, if a design activity takes 2 weeks, then execute Plan A, otherwise (else) execute Plan B.

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whereas it does not matter as much around the mean duration from the simulation.

Updating and Documenting a Schedule Risk Analysis

A schedule risk analysis should be performed on the schedule periodically as the schedule is updated to reflect actual progress on activity durations and sequences. As the project progresses, risks will retire or change in potential severity and new risks may appear. The length of time between SRA updates will vary according to project length, complexity, risk, and availability of management resources. A contractor should perform an SRA during the formulation of the performance measurement baseline to provide the basis for contractor schedule reserve at the desired confidence level. Preferably, an SRA would also be performed at key decision points throughout the project. An SRA might occur more regularly, for instance, to support annual budget request submissions so that adequate contingency can be included in the budget baseline.

SRAs should also be performed as needed, as when schedule challenges begin to emerge with a contractor and schedule contingency is consumed at a higher-than-expected rate or consumed by the materialization of risks not included in the risk register. An updated SRA is particularly important in order to support the internal independent assessment process if the project is rebaselined or if significant changes are made to the risk register. Keeping the project schedule current is discussed in Best Practice 9 and rebaselining is discussed in Best Practice 10.[29]

Each update to the SRA should be fully documented to include the risk data, sources of risk data, and techniques used to validate the risk data. In addition, the methodologies used to perform the simulation should be detailed, and outputs such as a prioritized risk list, the likelihood of the project completion date, the activities that most often ended up on the critical path, and the derivation of contingency sufficient for risk mitigation should be documented.

[29]If activities representing schedule contingency are not removed before conducting an update to the SRA, they will adversely affect the results.

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Best Practices Checklist: Conducting a Schedule Risk Analysis

- A schedule risk analysis was conducted to determine
  - the likelihood that the project completion date will occur,
  - how much schedule risk contingency is needed to provide an acceptable level of certainty for completion by a specific date,
  - risks most likely to delay the project,
  - how much contingency reserve each risk requires, and
  - the paths or activities that are most likely to delay the project.
- The schedule was assessed against best practices before the simulation was conducted. The schedule network clearly identifies work to be done and the relationships between detailed activities and is based on a minimum number of justified date constraints.
- The SRA has low, most likely, and high duration data fields.
- The SRA accounts for correlation in the uncertainty of activity durations.
- Risks are prioritized by probability and magnitude of impact.
- The risk register was used in identifying the risk factors potentially driving the schedule before the SRA was conducted.
- The SRA data and methodology are available and documented.
- The SRA identifies the activities in the simulation that most often ended up on the critical path, so that near-critical path activities can be closely monitored.
- The risk inputs have been validated. The ranges are reasonable and based on information gathered from knowledgeable sources, and there is no evidence of bias in the risk data.
- The baseline schedule includes schedule contingency to account for the occurrence of risks. Schedule contingency is calculated by performing an SRA and comparing the schedule date with that of the simulation result at a desired level of certainty.
- Schedule contingency is held by the project manager and allocated to contractors, subcontractors, partners, and others as necessary for their scope of work.
- Contingency is allocated according to the prioritized risk list because the risks that will actually occur and the magnitudes of their effects are not known in advance.
- The program documents the derivation and amount of contingency set aside by management for risk mitigation and unforeseen problems. An assessment of schedule risk is performed to determine whether the contingency is sufficient.
- An SRA is performed on the schedule periodically as the schedule is updated to reflect actual progress on activity durations and sequences. A contractor performs an SRA during the formulation of the performance measurement baseline to provide the basis for contractor schedule reserve at the desired confidence level.

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Best Practice 9: Updating the Schedule Using Actual Progress and Logic

Best Practice 9: Progress updates and logic provide a realistic forecast of start and completion dates for program activities. Maintaining the integrity of the schedule logic at regular intervals is necessary to reflect the true status of the program. To ensure that the schedule is properly updated, people responsible for the updating should be trained in critical path method scheduling.

"Statusing" is the process of updating a plan with actual dates, logic, and progress and adjusting forecasts of the remaining effort. Statusing the schedule is fundamental to efficient resource management and requires an established process to provide continual and realistic updates to the schedule. Updates should be regular and fully supported by team members and program management.

The benefits of updating the schedule on a regular basis include

- Knowledge of whether activities are complete, in progress, or late and the effect of variances on remaining effort;
- continually refined duration estimates for remaining activities using actual progress, duration, and resource use;
- the current status of total float and critical path activities; and
- the creation of trend reports and analyses to highlight actual and potential problems.

The time between status updates depends on the project's duration, complexity, and risk. Updating the schedule too often will misuse team members' time and will provide little value to management, but updating too infrequently makes it difficult to respond to actual events. The schedule may be updated less frequently in the beginning of a project, then more frequently as it progresses and as more resources begin working on activities.

The schedule should reflect actual progress as well as actual start and finish dates. Once an update has been made, management should assess its accuracy to verify that all finished work is in the past and all unfinished work is scheduled for the future.

To ensure that the schedule is properly updated, responsibility for changing or statusing the schedule should be assigned to someone who has the proper training and experience in CPM scheduling. Certain scheduling software packages may appear to be easy to use at first, but a schedule constructed by an inexperienced user may hide or ignore fundamental network logic errors and erroneous statusing assumptions.

Statusing the schedule should not be confused with revising the schedule. Statusing involves updating the schedule with actual facts and comparing those facts against a plan, such as events on certain dates and the progress of work with a certain number of resources. After the schedule is statused, management may wish to revise the plan for remaining work by, for example, changing the sequence of activities or adding or deleting activities. That is, statusing the schedule involves

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updating the schedule with actual data, while revising the schedule focuses on adjusting future work. The concepts of altering the plan based on knowledge gained or actual performance are referred to as either replanning or rebaselining, depending on the project's approach to change control. These concepts are discussed further in Best Practice 10.

Statusing Progress

Statusing progress generally takes the form of updating to either durations or work and includes updating the status of remaining work and network logic. A status date (or data date) denotes the date of the latest update to the schedule and thus defines the demarcation between actual work performed and remaining work. All work prior to the status date represents completed effort; all work beyond it represents remaining effort. Simply put, all dates before the status date are in the past and all dates beyond the status date are in the future. No dates in the past should be estimated; no dates in the future are actual dates.

Unless a status date is provided, the schedule cannot be used to reliably convey past and remaining effort. The status date is an input into the calculations used to update and schedule remaining work. Neither the date on which someone is viewing the schedule nor the latest save date should be used as a substitute for a valid status date (see case study 17).

Case Study 17: Invalid Status Dates, from *DOD Business Transformation,* GAO-11-53

Our analysis of the Air Force Defense Enterprise Accounting and Management System IMS found that the contractor schedule did not have a status date (or data date), and that the government program management office did not expect one. A status date denotes the date of the latest update to the schedule and, thus, defines the point in time at which completed work and remaining work are calculated. Officials stated that the status date is reflected by the month given in the schedule file name. Despite the invalidity of using the file name for a status date, we found 31 activities that had actual starts in future months relative to the month in the file name. That is, according to the schedule, these activities had actually started in the future. For example, the schedule file name is November 2009, yet we found actual start dates for activities in December 2009, February 2010, and April 2010.

GAO, *DOD Business Transformation: Improved Management Oversight of Business System Modernization Efforts Needed,* GAO-11-53 (Washington, D.C.: October 7, 2010).

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Updating Duration of Work

Updating duration is the most common method of recording progress because it is the easiest to do. To update activity duration, an actual duration is entered into the plan to record the amount of time (typically working days) elapsed since the last update. If the activity began after the last statusing, an actual start date is entered as well. Next, an updated estimate of time remaining on the activity is entered. The scheduling software calculates percentage complete for the activity based on actual duration and planned remaining duration.

While duration updates are widely used, team members can easily misconstrue them. Because the update applies to the activity duration, it specifically denotes the passage of time from the start date, not actual work accomplished on the activity. For instance, an activity could have used up 80 percent of its scheduled time yet have accomplished only 10 percent of the work. For this reason, it is important that realistic forecasts of remaining duration be updated at the same time as the actual duration is recorded.

Accordingly, updating an activity's duration by entering percentage complete is not recommended, because scheduling software will adjust the remaining duration in order to yield the entered percentage complete. Estimating a percentage of work or time complete is an inexact science, whereas activity managers and schedulers are accustomed to estimating remaining duration. For instance, task managers may confuse inputs and outputs, assuming that if they have worked 7 days on a 10-day activity, they must be 70 percent finished. In addition, asking activity managers for information on actual duration and remaining duration is a more natural question than requesting a subjective measure of time passed. For example, a response of 80 percent complete on a 5-day activity may indicate that it is almost finished, even if the team has left all the difficult work for the last day.

The subjectivity of percentage complete estimates becomes more apparent the longer the activity's duration. While 25 percent complete may be a viable estimate for a 4-day activity, it is an entirely ambiguous progress measure for a 50-day activity. Finally, percentage complete is based on the expected duration of an activity, which is variable. The exception is in updating LOE activities that represent support activities that are not associated with any discrete product. Level of effort activities are typically described as percentage complete by the total duration of the activities they support. However, LOE activities are best linked to the physical percentage complete of the work they support. For example,

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quality control responsibilities associated with pipefitting or pouring concrete should be hammocked with their respective activities, and the LOE efforts should be based on the work's physical percentage complete, not the elapsed time.

Updating durations generally implies that work performed by a single resource or multiple assigned resources is completed at the same pace and, in terms of percentage complete, is equal to the time spanning the start date and the status date. That is, if the activity is 50 percent complete, then all assigned resources are generally assumed to have completed 50 percent of their work. This is a simplifying assumption that may work well for some program plans.

Other program managers may wish to update work by resources to track actual effort by resource unit or group. Tracking actual work progress requires more time and is more complex than updating durations, but it provides more accurate historical data and higher-quality forecasts of remaining effort. Similar to updating durations, updating work progress requires entering actual work performed as well as forecasts for remaining work. The scheduling software then calculates percentage work complete.

Regardless of whether a schedule's progress is marked by duration or work, data should be relevant and should adhere to the definitions set forth in the governing process. Team members and management should have consistent, documented definitions of what constitutes an activity's start, its finish, and its meaningful progress. For example, the actual start date of an activity could be the preparatory research or it could mean only the start of significant work that directly affects the associated product. Likewise, the actual finish date could be the point at which no further work whatsoever is charged to that particular activity or it could simply mean the point at which the activity's successor can begin. In general, opening an activity without the resources to do the work just to record some progress is a poor practice.

Updating the Status of Remaining Work

Time preceding the status date represents history. All unfinished work and activities that have not started should be rescheduled to occur on or after the status date. If unfinished work remains in the past, the schedule no longer represents a realistic plan for completing the project, and team members will lose confidence in the model. Case study 18 shows an example of activities within a schedule that were not properly updated.

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Case Study 18: Updating a Schedule Using Progress and Logic, from *Aviation Security,* GAO-11-740

Officials from the Transportation Security Administration's Electronic Baggage Screening Program stated that they had conducted weekly meetings on the schedule and had updated the status accordingly. From these weekly meetings, officials generated weekly reports that identified key areas of concern with regard to schedule shifts and their potential effects on milestones. However, our analysis showed that 30 activities (6 percent of the remaining activities) should have started and finished according to the schedule status date but did not have actual start or actual finish dates.

In addition, the schedule's critical path began in a data collection activity that was not logically linked to any predecessor activities, had a constrained start date, and was marked as 100 percent complete on June 18, 2010—2 months into the future, according to the schedule status date of April 16, 2010.

The schedule also contained 43 activities (9 percent of the remaining activities) with actual start and actual finish dates in the future relative to the schedule status date.

The schedule should be continually monitored to determine when forecasted completion dates differ from the planned dates, which can be used to determine whether schedule variances will affect downstream work.

GAO, *Aviation Security: TSA Has Enhanced Its Explosives Detection Requirements for Checked Baggage, but Additional Screening Actions Are Needed,* GAO-11-740 (Washington, D.C.: July 11, 2011).

Progress Records

Schedules should be statused by reference to progress records for the current time period. Progress records are the sources from which schedulers update the schedule. They are a documentation trail between actual experience on the activity and the progress recorded in the schedule, including actual start and finish dates, the number of resources required, and the amount of work performed to accomplish the activity. Progress records can take many forms according to individual agency or contract requirements. Typically, the document that keeps the activity owner aware of information related to current and upcoming activities is the same form that is filled out with actual data by the owner and returned to the scheduler for updating the schedule (commonly known as a "turnaround" document). This document contains pertinent activity information such as its name, unique ID, original and remaining durations, planned and actual start and finish dates, and float. For the purposes of

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updating the schedule for the current progress period, the progress record should include, at a minimum,

- the actual start date if started or the planned start date if not started;
- the actual finish date if finished or the planned finish date if not finished;
- actual duration or actual work performed;
- an estimate of the remaining duration or remaining work; and
- an estimate of percentage complete for LOE activities.

It is important to collect the correct type of data during statusing. Individuals directly managing or performing the work should report progress. If activities are updated by duration, team members should not provide work updates; likewise, if activities are updated by work, team members should not provide duration updates.

Progress records are particularly useful for reviewing remaining duration estimates during attempts to accelerate the schedule (this concept is discussed in Best Practice 10). Upon completion of the project, progress records will provide the historical data necessary for resource, work, and productivity assumptions for future analogous projects. If sufficient attention is paid to recording the way work is actually performed, the resulting archived data will lead to improved accuracy and quality control of similar future projects.

Adding Activities

Activities may be added to represent unplanned work, reflect the actual order of completion of planned work, or refine existing long-duration activities. As with all existing activities, new activities should be given a unique description and be mapped to the appropriate activity codes. New activities should be reviewed for completeness of predecessor and successor logic, resource assignments, and the impacts on the critical path and float calculations. Inserting additional activities may be subject to the program's schedule change control process.

Out-of-Sequence Logic

Rescheduling activities may require adjusting network logic to explain why an activity did not start as planned, particularly if any of its successors have started or been completed. An activity's starting before its predecessor activity has completed is out-of-sequence progress. Out-of-sequence progress is common and should be expected, because some activity managers know they can safely start their activities, sometimes challenging their predecessor activity teams to speed up.

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When out-of-sequence progress occurs, managers and schedulers may choose to retain or override the existing network logic.

Retained Logic

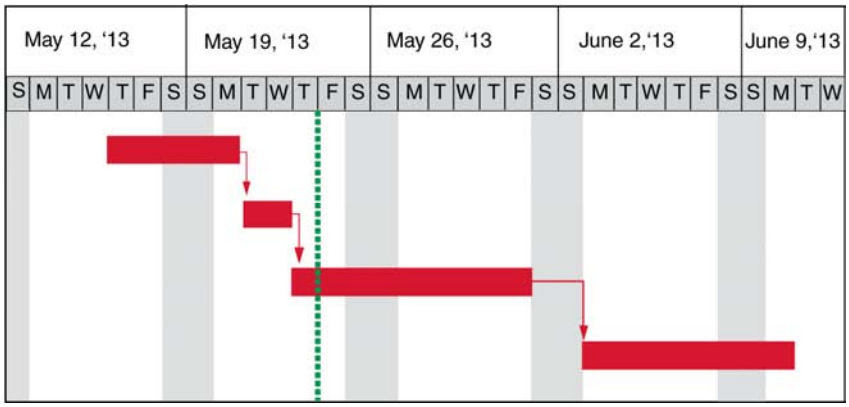
In the case of retained logic, work on the activity that began out of sequence is stopped until its predecessor is completed. As much as possible of the original network logic is preserved because the remainder of the out-of-sequence activity is delayed until the predecessor finishes, to obey its original sequence logic.

Progress Override

In progress override, work on the activity that began out of sequence is permitted to continue, regardless of original predecessor logic. Actual progress in the field supersedes the plan logic, and work on the out-of-sequence activity continues. The predecessor and successor activities may now be executed in parallel, or the original logic on the activities is altered to model their new, more realistic, dependencies. Figure 44 shows the original plan for conducting the interior finishes of the house construction project.

Figure 44: The Original Plan for Interior Finishing

Activity name	Start	Finish
Install tile in bathroom and kitchen	5-16-13	5-20-13
Install interior doors	5-21-13	5-22-13
Install interior door, window, and baseboard trim	5-23-13	5-31-13
Install carpeting and wood flooring	6-3-13	6-10-13



Source: GAO.

For this example, we will assume that the status date is May 23 and that "install tile in bathroom and kitchen" has completed on time. No progress was made on "install interior doors" so its start date is rescheduled for May 24. However, its successor activity "install interior door, window, and baseboard trim" did start on May 22 and two carpenters accomplished 32 hours of work. This is illustrated in figure 45 by the status date (green vertical dashed line) and white activity bars that represent actual

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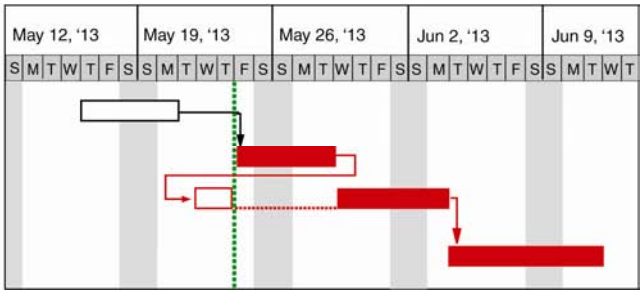
accomplished effort. If the schedule is statused according to retained logic, the remaining work for “install interior door, window, and baseboard trim” is deferred until the interior doors are installed. In figure 45, 2 days of actual duration is recorded for the “install interior door, window, and baseboard trim” activity, but the remaining duration is rescheduled to begin after “install interior doors” finishes. This start-stop-resume approach may not be an efficient way to install interior trim but it may be viewed as important given the reliance of the trimming activity on the installation of interior doors.

Figure 45: Retained Logic

Activity name	Start	Finish	Actual start	Actual finish	Duration (in days)	Actual duration (in days)
Install tile in bathroom and kitchen	5-16-13	5-20-13	5-16-13	5-20-13	3	3
Install interior doors	5-24-13	5-28-13	NA	NA	2	0
Install interior door, window, and baseboard trim	5-22-13	6-3-13	5-22-13	NA	6	2
Install carpeting and wood fooring	6-4-13	6-11-13	NA	NA	6	0



Source: GAO.

If the schedule is statused according to progress override, the work for “install interior door, window, and baseboard trim” continues, regardless of the original plan’s logic. This concept is illustrated in figure 46. Two days of actual duration is recorded for the trimming activity, and the remaining duration is scheduled to occur in parallel with “install interior doors.” While the progress override accelerates the overall construction schedule by 2 working days, the time savings may not be feasible for at least three reasons. First, it assumes that “install interior door, window, and baseboard trim” does not depend on “install interior doors” finishing as the original plan dictated. Second, it assumes that resources are available to work on both the interior door installation and the interior trim installation. But both activities rely on two carpenters; the concurrent activities now require four carpenters on May 24 and May 28. Finally, the installation of carpeting and wood flooring, originally scheduled to begin on June 4, is now scheduled to start on May 31. It may be unrealistic to assume that the flooring material and the floor installers will be available 2 days earlier than expected with less than a week’s notice.

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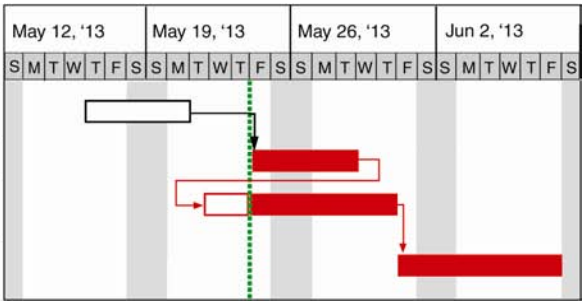
Figure 46: Progress Override

Activity name	Start	Finish	Actual start	Actual finish	Duration (in days)	Actual duration (in days)
Install tile in bathroom and kitchen	5-16-13	5-20-13	5-16-13	5-20-13	3	3
Install interior doors	5-24-13	5-28-13	NA	NA	2	0
Install interior door, window, and baseboard trim	5-22-13	6-30-13	5-22-13	NA	6	2
Install carpeting and wood fooring	5-31-13	6-7-13	NA	NA	6	0



Source: GAO.

Note: NA = Not applicable.

In general, regardless of how management wishes to proceed with the work related to the out-of-sequence activity, the logic relationship between activities in the schedule should be repaired to show the order in which the activities were actually carried out. If the original logic is allowed to remain, it will produce an inaccurate schedule. For example, the F–S logic between the “install interior doors” and “install door, window, and baseboard trim” activities should be deleted. The successor logic of “install interior doors” should be reviewed and linked to a new correct successor, perhaps “install carpeting and wood floors.”

Retained logic and progress override are options in scheduling software that must be properly set before updating the status of the schedule. Each approach represents a different philosophy on how to manage unexpected developments in the project, and they can have vastly different effects on forecasted dates. It is recommended that the scheduler and activity leads examine each instance of out-of-sequence progress to determine the correct response case by case. While out-of-sequence activities are common, they should nonetheless be reported, and an analysis of the effect on key milestone dates is recommended before out of sequence activities are formally addressed. Out-of-sequence activities may represent risk or potential rework, because knowledge or products from the predecessor activity were not complete and available to the successor activity.

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Verifying Status Updates and Schedule Integrity

Once the schedule has been statused, management should review the inputs to verify the updates and assess the effect on the plan. The schedule should be reviewed to ensure the following:

- All activities completed prior to the status date represent finished work and therefore should have actual start and finish dates. They should be statused as 100 percent complete with actual durations or actual work values.
- In-progress activities should have an actual start date and all work scheduled before the status date is expressed as actual duration or actual effort. All remaining work should be scheduled beyond the status date.
- Activities planned beyond the status date represent future activities and therefore should not have actual start or actual finish dates. They also should not have actual duration or work values.
- Out-of-sequence activities are addressed purposefully and case by case through either retained logic or progress override.
- Schedule recalculations from changes in estimated work, assigned resources, or duration are verified to ensure meaningful and accurate calculations.
- Resource assignments are assessed for the coming period, and assignments for delayed or out-of-sequence activities are reevaluated for potential overallocations. In addition, resource calendars should be updated to reflect current availability.
- Date constraints are revisited and removed if possible. In particular, soft constraints should be removed if they can no longer affect an activity's start or finish date.
- At least one in-progress activity is critical. If not, it is most likely that date constraints or external dependencies are separating subsequent from the in-progress activities. Such breaks in the critical or longest path represent weak or incomplete logic, causing a lack of credibility in the identity of the path and the schedule dates.

Schedule integrity should also be assessed in the schedule update process. Verifying the integrity of the schedule after each update will ensure that the schedule remains reliable after activities are added, removed, broken down into smaller activities, or sequenced differently from the last period. Common schedule health measures are listed in appendix III.

It is unlikely in a major program that all activities will be fully identified. As a program changes and completes phases, some activities are overtaken by events and others are generated from lessons learned. Changes made to a schedule, whether minor or major, may need to undergo formal

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change control according to contract requirements or internal process controls.

The current schedule, once management approves it, should be assigned a version number and archived. This ensures that all status updates can be traced and guarantees that all stakeholders are using the same version of the current schedule.

Schedule Narrative

Regardless of whether a change triggers schedule change control, all changes made to the schedule during statusing should be documented, and salient changes should be justified along with their likely effect on future planned activities. A schedule narrative should accompany the updated schedule to provide decision makers and auditors a log of changes and their effect, if any, on the schedule timeframe. The scope of the schedule narrative will vary with project and contract complexity but should contain, at a minimum,

- the status of key milestone dates, including the program finish date;
- the status of key hand-offs or giver/receiver dates;
- explanations for any changes in key dates;
- changes in network logic, including lags, date constraints, and relationship logic, and their effect on the schedule;
- a description of the critical paths, near-critical paths, and longest paths along with a comparison to the previous period's paths; and
- a description of any significant scheduling software options that have changed between update periods, such as the criticality threshold for total float and progress override versus retained logic and whether or not resource assignments progress with duration.

Significant variances between planned and actual performance, as well as actual and planned logic, should be documented and understood. Assessing the updated critical path is particularly crucial. It should be compared to the critical path from the baseline and the last period's current schedule and assessed for reasonableness. Total float should be examined and compared to the last period's current schedule to identify trends. For activities that are behind schedule, the remaining duration should be evaluated and the delay's effect on succeeding activities in the network should be understood. If a delay is significant, management should develop a plan to examine the options to recover from the schedule slip. In addition, near-critical paths should be assessed and compared against previous near-critical paths. A decrease in total float values on a near-critical path indicates activities that are slipping; the path

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may soon be critical, because float will not be available for successive activities on that path.

Reporting and Communication

As noted earlier, a schedule is a fundamental program management tool that specifies when work will be performed in the future and how well the program is performing against an approved plan. It is therefore particularly important that all stakeholders be able to view information stored in the schedule related to their specific roles and needs in order to successfully manage and execute the plan. Stakeholders include, among others, project team members, control account managers, government customers, resource managers, subcontractors, project sponsors, finance specialists, and decision makers. Each stakeholder requires a different level and type of information that will depend on whether the stakeholder is internal to the project or external. Reports can encompass actual data (status), actual versus planned data (progress), and predictive data (forecasts). A well-constructed, comprehensive schedule is a database that contains actual, planned, and forecast activity and resource and cost information. It will be able to report reliable data quickly at all levels of detail.

The regularity of schedule reporting and the level of detail that is reported will naturally vary by stakeholder and project complexity. At the level of senior decision maker, high-level summary trend charts and key milestone schedules reporting monthly or quarterly progress will be most useful. These reports typically include progress and forecast information on contractual and deliverable milestones and major project phases, as well as summary critical path and contingency information. High-level trend information is also useful, such as key milestone completions, contingency burn rate, and resource availability. In addition, the level of detail will depend on the complexity and risk of certain WBS items. For example, a series of complex activities on the critical path may be reported to program management in more detail than less complex, noncritical activities.

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Best Practices Checklist: Updating the Schedule Using Actual Progress and Logic

- Schedule progress is recorded periodically and the schedule has been updated recently. Schedule status is updated with actual and remaining progress.
- Schedule status is based on progress records for the current time period; they include pertinent activity information such as name, unique ID, original and remaining durations, planned and actual start and finish dates, and float.
- The status date (or data date) denoting the date of the latest update to the schedule is recorded.
- At least one in-progress activity is critical.
- No activities precede the status date without actual start or finish dates and actual effort up to the status date. No activities beyond the status date have actual start or finish dates or actual effort.
- Activities that are behind schedule by the status date have a remaining duration estimate and the delay's effect has been assessed.
    - If the delay is significant, plans to recover the implied schedule slip have been evaluated and implemented, if so decided.
    - Resources are reviewed and may be reassigned, depending on schedule progress.
- When possible, LOE activities are linked to the physical percentage complete of the work they support.
- When possible, actual work progress is tracked rather than simply updating durations.
- Responsibility for changing or statusing the schedule is assigned to someone who has the proper training and experience in CPM scheduling.
- Changes that were made to the schedule during the update have been documented.
- New activities are reviewed for completeness of predecessor and successor logic, resource assignments, and effects on the critical path and float calculations.
- Activities that have started or completed out of sequence have been addressed using either retained logic or progress override to reflect the order in which the activities were actually carried out.
- Management reviews schedule updates and verifies and assesses effects on the plan. Significant variances between planned and actual performance, as well as actual and planned logic, are documented and understood.
- The schedule structure is examined after each update to ensure that logic is not missing or broken, all date constraints are necessary, and no artifacts impede the ability of the schedule to dynamically forecast dates.

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- The current schedule, once management approves it, is assigned a version number and archived.
- A schedule narrative accompanies each status update and includes
  - the status of key milestone dates, including the program finish date;
  - the status of key hand-offs or giver/receiver dates;
  - explanations for any changes in key dates;
  - changes in network logic, including lags, date constraints, and relationship logic and their effect on the schedule;
  - a description of the critical paths, near-critical paths, and longest paths along with a comparison to the previous period's paths; and
  - any significant scheduling software options that have changed between update periods, such as the criticality threshold for total float; progress override versus retained logic; or whether resource assignments progress with duration.

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Best Practice 10: Maintaining a Baseline Schedule

Baseline and Current Schedules

Best Practice 10: A baseline schedule is the basis for managing the project scope, the time period for accomplishing it, and the required resources. The baseline schedule is designated the target schedule, subject to a configuration management control process, against which project performance can be measured, monitored, and reported. The schedule should be continually monitored so as to reveal when forecasted completion dates differ from planned dates and whether schedule variances will affect downstream work. A corresponding baseline document explains the overall approach to the project, defines custom fields in the schedule file, details ground rules and assumptions used in developing the schedule, and justifies constraints, lags, long activity durations, and any other unique features of the schedule.

Establishing a baseline schedule is a strong support to effective management. A baseline schedule represents the original configuration of the program plan and signifies the consensus of all stakeholders regarding the required sequence of events, resource assignments, and acceptable dates for key deliverables. It is consistent with both the project plan and the project budget plan and defines clearly the responsibilities of project performers. The baseline schedule includes not only original forecasts for activity start and finish dates but also the original estimates for work, resource assignments, critical paths, and total float.

The baseline schedule is not the same as the current schedule. The current schedule is updated from actual performance data, as described in Best Practice 9. Therefore, it provides the latest depiction of performance and accomplishments, along with the latest forecast of remaining dates and network logic. The baseline schedule represents the program's commitments to all stakeholders, while the current schedule represents the actual plan to date.

The current schedule is compared to the baseline schedule to track variances from the plan. Deviations from the baseline inform management that the current plan is not following the original plan as agreed on by all stakeholders. Deviations imply that the current approach to executing the project needs to be altered to align the program to the original plan or that the plan from this point forward should be altered.

Comparing the current status of the schedule to the baseline schedule can help managers identify the root cause of the deviation, thereby allowing them to target specific areas such as resource assignments, network logic, and other factors for immediate mitigation. Without a formally established baseline schedule to measure performance against, management lacks the ability to identify and mitigate the effects of unfavorable performance.

The final version of the current schedule—the "as-built" schedule—represents the plan as executed to completion. Particular care should be taken to archive this final version. Once the project has been completed, the as-built schedule becomes a database of the actual sequence of events, activity durations, required resources, and resource productivity. These can be compared to the original plan for an assessment of lessons learned, and the data become a valuable basis of estimate input for schedule estimates of future analogous projects.

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As-built schedules are also useful for creating and validating fragmentary networks, or "fragnets." A fragnet is a subordinate network that represents a sequence of activities typically related to repetitive effort. Subordinate networks can be inserted into larger networks as a related group of activities. For example, a related group of activities may occur for each systems test, regardless of the actual product. In this case, a fragnet related to systems test, representing a well-known sequence of events and expected duration, may be inserted into various product schedules.

The baseline should be set promptly after a program begins. A schedule baseline is typically in place between 3 and 6 months of contract award, although the timing will depend on contract size and type, requirements, and risk.[30] Projects should operate against an interim baseline until the schedule baseline is in place. The level of detail in the baseline schedule also depends on contract type, industry type, risk, and agency guidelines. For example, management may choose to baseline the entire detailed IMS or only intermediate-level summary activities leading to key milestones. The greater the baselined detail, the greater will be the understanding of performance, variances, forecasts, and assessed effects of potential changes—yet this must be balanced with the time necessary to formally approve, change, and track at that level.

In addition, baseline creation and approval may take place in concert with the project's rolling wave process. That is, as periods of summary and intermediate-level planning packages are planned in greater detail, the baseline is updated to reflect that detail. The intent is that once formally approved and archived, the baseline schedule reflects the agency's commitment to allocating resources and becomes the basis against which actual performance and accomplishments can be measured, monitored, and reported. The parties should agree that the baseline refers to the maintenance of a schedule for meeting contractual deliverable and project control milestones. It typically does not constitute a strict

[30]Establishing and maintaining a schedule baseline is highly significant when EVM is a requirement. In this case, the entire schedule must be baselined because the IMS is the source of time-phasing for all control accounts and work packages that make up the project's performance measurement baseline. This requirement will apply to contracted effort and may apply to the government effort as well, depending on the agency. For contracted efforts, the baselines for cost and schedules are required to support the integrated baseline review (IBR). In reality, to successfully prepare for the IBR, baselines must be set (either formally or informally) much earlier than the IBR deadline to ensure credibility.

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adherence to estimates of activity durations, resources assignments, or logic.

Baseline Document

The accuracy of the IMS as a model for the project depends on a mutual understanding among all stakeholders of the schedule's structure, use, and underlying assumptions. Thorough documentation is essential for validating and defending a baseline schedule. A well-documented schedule can present a convincing argument for a schedule's validity and can help answer decision makers' and oversight groups' probing questions. A well-documented schedule is essential if an effective independent review is to ensure that it is valid and credible.

A schedule baseline document is a single document that defines the organization of the IMS, describes the logic of the network, describes the basic approach to managing resources, and provides a basis for all parameters used to calculate dates. As noted in Best Practice 1, the government program management office is responsible for integrating all government and contractor work into one comprehensive program plan. The schedule baseline document is therefore created and approved by the government program management office once the schedule baseline is approved. While the baseline document will not be updated as often as the schedule narrative described in Best Practice 9, it should be considered a living document in that it reflects updates to the baseline schedule. Both the baseline schedule and baseline document should be referenced and updated as the project progresses in accordance with the established change process. At a minimum, the baseline document should include the following.

- A project overview or a general description of the project, including general scope and key estimated life cycle dates, and descriptions of each stakeholder, including the project owner, prime and subcontractors, and key stakeholder agencies.
- A general description of the overall execution strategy, including the type of work to be performed, and contracting and procurement strategies.
- A description of the overall structure of the IMS, including the scope and purpose of subprojects, those responsible for each subproject, the relationship between subprojects, a WBS dictionary, the status delivery dates for each subproject, and a list of key hand-off products and their estimated dates. In addition, it refers to relevant contract data requirements lists (CDRLs) and data item descriptions (DIDs) associated with schedules.

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- A description of the settings for key options for the relevant software, such as criticality threshold, progress override versus retained logic, and the calculation of critical paths and whether work progresses with duration updates.
- A definition and justification in the baseline document of all ground rules and assumptions used to develop the baseline, including items specifically excluded from the schedule. If rolling wave planning is used, key dates or milestones for detail and planning periods are defined.
- A justification of each use of a lag and date constraint that is clearly associated with the activities that are affected. Missing successor or predecessor logic is also justified.
- The documentation of each project, activity, and resource calendar, along with a rationale for workday exceptions (holidays, plant shutdowns, and the like), working times, and planned shifts.
- An explanation or rationale for the basic approach to estimating key activity durations and justification of the estimating relationship between duration, effort, and assigned resource units, to an appropriate level of detail.
- Definitions of all acronyms and abbreviations.
- A table of the purposes of custom fields. Any LOE activities in the IMS are clearly marked.
- A description of resources used in the plan and the basic approach for updating resource assignments, along with schedule updates and average and peak resource demand projections. The document defines all resource groups used within the schedule and justifies planned overallocations to an appropriate level of detail. In addition, key material and equipment resources are described in the context of their related activities.
- A description of critical paths, longest paths, and total float. A discussion of the critical paths, including justification for the criticality threshold, rationale for single or multiple critical paths, and justification for any gaps in a noncontinuous critical path. If the schedule has late-date constraints, a description of the longest path is included. In addition, abnormally large amounts of total float are justified.
- A description of the critical risks as prioritized in a quantitative schedule risk analysis, along with a discussion of the appropriate schedule contingency.
- A detailed description of the updating and schedule change management processes. Any additional documentation that governs them is referenced.

Thorough documentation helps with analyzing changes in the program schedule and identifying the reasons for variances between estimates

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and actual results. In this respect, baseline documentation contributes to the collection of cost, schedule, and technical data that can be used to support future estimates.

The Change Process

The baseline and current schedules should be subjected to a change control process. A control process governs when and how technical and programmatic changes are applied to the baseline, as well as the content of the current IMS. A proper change control process helps ensure that the baseline and current schedule are accurate and reliable. Without a documented, consistently applied schedule change control process, project staff might continually revise the schedule to match performance, hindering management's insight into the true performance of the project. Undocumented or unapproved changes hamper performance measurement and may result in inaccurate variance reporting, inconsistent stakeholder versions of the plan, and unreliable schedule data. Moreover, if changes are not controlled and fully documented, performance cannot be accurately measured against the original plan.

The extent to which the IMS is subject to a change control process is decided by program management and depends on the project size, scope, risk, and complexity. Less complex projects may subject only key milestones or high-level WBS activities to the change control process, so that changes to supporting detailed activities do not require change approval. For more complex and tightly controlled schedules, lower-level detail activities as well as network dependencies may also be subject to change approval.

The current schedule, once management approves it, should be assigned a version number and archived. This ensures that all status updates can be traced and guarantees that all stakeholders are using the same version of the current schedule.

Changes to the baseline schedule should be limited to revisions for new or reduced scope or for formal replanning. At times, however, management may conclude that the remaining schedule target for completing a program is significantly insufficient and that the current baseline is no longer valid for realistic performance measurement. The purpose of a schedule rebaselining is to restore management's control of the remaining effort by providing a meaningful basis for performance management.

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Working to an unrealistic baseline could make an unfavorable schedule condition worse. For example, if variances become too big, they may obscure management's ability to discover newer problems that could still be mitigated. To quickly identify new variances, a schedule rebaseline normally eliminates historical variances. A rebaselined schedule should be rare. If a program is recurrently rebaselined, it may be that the scope is not well understood or simply that program management lacks effective discipline and is unable to develop realistic estimates. Case study 19 highlights a complex, highly detailed schedule that was successfully updated periodically according to a defined process.

Case Study 19: Baseline Schedule, from *2010 Census,* GAO-10-59

For the 2010 Decennial Census schedule, the U.S. Census Bureau had implemented processes around its master schedule that complied with a number of scheduling process criteria that are important to maintaining a schedule that is a useful management tool. The Bureau ensured a complete scope of the schedule with input from stakeholders throughout the agency, with reviews of previous schedules, that built on a number of census tests during the decade. As a result, the schedule was the primary source for senior managers to determine weekly what census activity was ahead of or behind schedule, and it provided a resource for determining any effect on the overall project of delays in major activities.

The Bureau had documented and implemented a formal process for keeping the data in the schedule current. Staff within each Bureau division were responsible for ensuring that schedule activities had their status updated weekly. Staff updated the actual start and finish dates, the percentage of each activity completed so far, and estimates of the time remaining to complete each activity in progress. The Bureau was recording status information on an average of more than 1,300 activities in the schedule ongoing during any given week, generating historical data that could provide valuable input to future schedule estimates.

In addition, the Bureau implemented a formal change control process that preserved a baseline of the schedule so that progress could be meaningfully measured. The Bureau's criteria for justifying changes were clearly documented and required approval by a team of senior managers and acknowledgment of the effect by each team affected within the Bureau. Since the master schedule was baselined in May 2008, about 300 changes had been approved. Even corrections to the schedule for known errors, such as incorrect links between activities,

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had to be approved through the change control process, helping to ensure the integrity of the schedule.

GAO, *2010 Census: Census Bureau Has Made Progress on Schedule and Operational Control Tools, but Needs to Prioritize Remaining System Requirements,* GAO-10-59 (Washington, D.C.: November 13, 2009).

Baseline Analysis

Schedules deviate from the baseline as a program is executed. Changes in resource availability, late or early key deliveries, unexpected additional work activities, and risks can contribute to deviation. Although they are often perceived as something bad, negative variances provide valuable insight into program risk and its causes. Positive variances can indicate problems as well. For example, early starts may cause issues with out-of-sequence logic and can disrupt the scheduling of future resources. Understanding the types of activities that have started earlier or later than planned is vital as well. For instance, positive variances may not be desirable if only relatively easily accomplished activities are completed early while critical activities continue to be delayed. Variances empower management to decide how best to handle risks. Schedule deviations from the baseline plan give management at all levels information about where corrective action is needed to bring the program back on track or to update completion dates.

A schedule variance does not necessarily mean program delay; it means that work was not completed as planned. Negative schedule variances should be investigated to see if the effort is on the critical path. If it is, then the whole program will be delayed. In addition, activities that vary significantly from their baseline may create a new critical path or near-critical path.

A schedule Gantt chart can be used to show baseline dates, forecasted dates, and actual progress to date for each activity, as shown in figure 47. In the figure, the gray activity bar shows the activity baseline dates. The black bar above the baseline dates represents forecasted dates, and the white bar represents actual effort to date, including the actual start date. The status date is represented by the vertical dashed green line. The difference between the baseline start date and the actual start date is the start variance; the difference between the baseline finish and forecasted finish is the (forecasted) finish variance.

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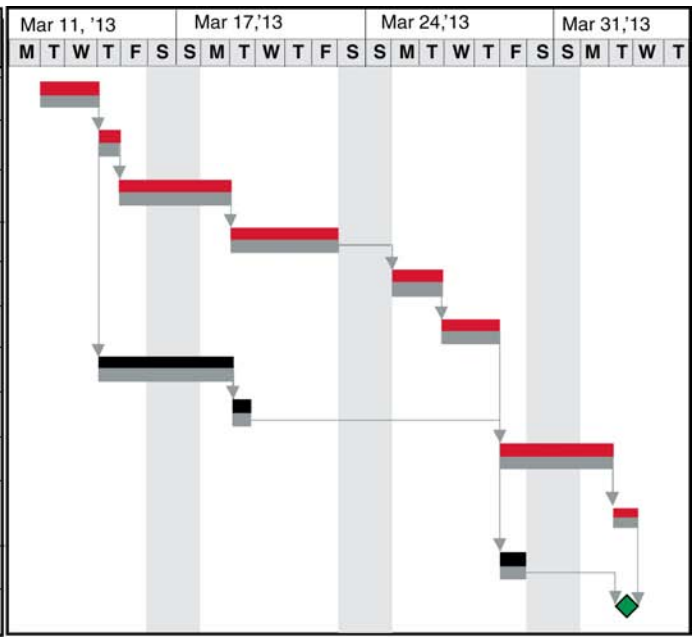
Figure 47: Baseline, Actual, and Forecasted Dates

Activity name	Start	Actual start	Total float (in days)
Install first floor joists and decking	3-12-13	NA	0
Install waterproofing on exterior basement walls	3-14-13	NA	0
Finish excavate and pour basement floor	3-15-13	NA	0
Frame first floor walls	3-19-13	NA	0
Install roof trusses	3-25-13	NA	0
Install roof decking	3-27-13	NA	0
Exterior backfill basement walls	3-14-13	NA	7
Rough grade property	3-19-13	NA	7
Form and pour driveway	3-29-13	NA	0
Finish excavate and pour garage floor	4-2-13	NA	0
Rough-in framing inspection	3-29-13	NA	2
Framing complete	4-2-13	NA	0



Source: GAO.

Carefully monitoring the schedule allows for quickly determining when forecasted completion dates differ from the planned dates. In this respect, progress to date can be evaluated on whether it has met or not met planned targets. Activities may be resequenced or resources realigned. It is also important to determine whether schedule variances are affecting successive work activities. For example, a schedule variance may compress remaining activities' durations or cause "stacking" of activities toward the end of the program, to the point at which it is no longer realistic to predict success.

Consider again the activities in the framing phase of the house construction project, given in figure 48. Red activities are forecasted to be critical and black activities will have 2 to 7 days of total float on their paths. The gray bars below the red and black activity bars represent the baseline start and finish dates. The original plan is for the installation of the first floor joists and decking to begin on March 12 and to complete framing by April 2. Before any progress is made on the project, baseline dates and forecast dates are the same.

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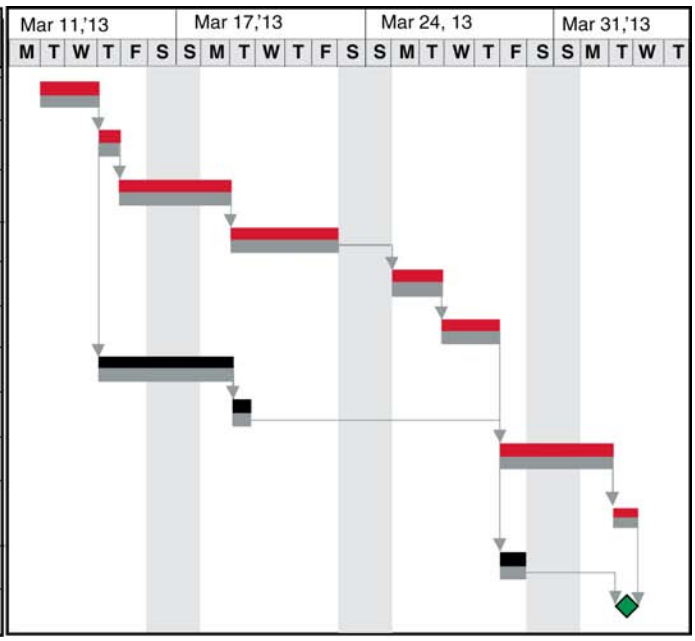
Figure 48: Baselined Activities

Activity name	Start	Actual start	Total float (in days)
Install first floor joists and decking	3-12-13	NA	0
Install waterproofing on exterior basement walls	3-14-13	NA	0
Finish excavate and pour basement floor	3-15-13	NA	0
Frame first floor walls	3-19-13	NA	0
Install roof trusses	3-25-13	NA	0
Install roof decking	3-27-13	NA	0
Exterior backfill basement walls	3-14-13	NA	7
Rough grade property	3-19-13	NA	7
Form and pour driveway	3-29-13	NA	0
Finish excavate and pour garage floor	4-2-13	NA	0
Rough-in framing inspection	3-29-13	NA	2
Framing complete	4-2-13	NA	0



Source: GAO.

Note: NA = Not applicable.

Figure 49 gives the current schedule for the same plan, now statused through March 25. The blue dashed vertical line represents the current status date, and the white horizontal bar on activities represents progress to date on each activity.

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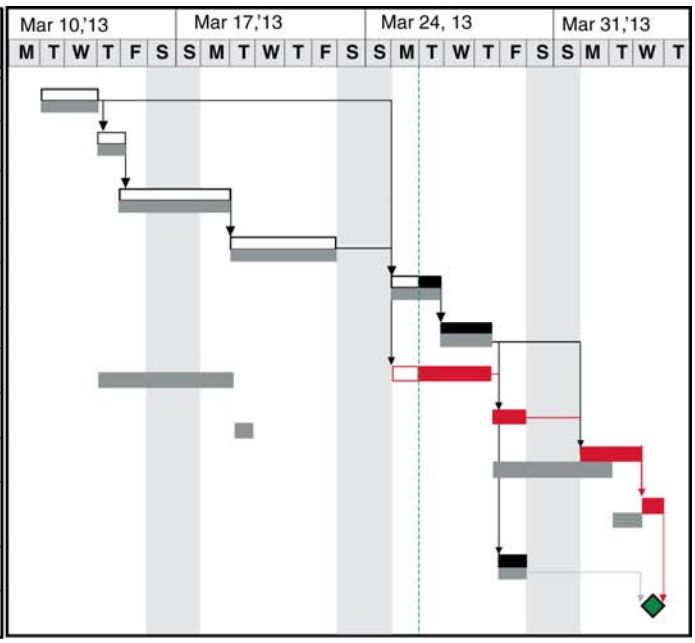
Figure 49: Updated Status Compared with Baseline

Activity name	Start	Actual start	Total float (in days)
Install first floor joists and decking	3-12-13	3-12-13	0
Install waterproofing on exterior basement walls	3-14-13	3-14-13	0
Finish excavate and pour basement floor	3-15-13	3-15-13	0
Frame first floor walls	3-19-13	3-19-13	0
Install roof trusses	3-25-13	3-25-13	1
Install roof decking	3-27-13	NA	1
Exterior backfill basement walls	3-25-13	3-25-13	0
Rough grade property	3-29-13	NA	0
Form and pour driveway	4-1-13	NA	0
Finish excavate and pour garage floor	4-3-13	NA	0
Rough-in framing inspection	3-29-13	NA	3
Framing complete	4-3-13	NA	0



Source: GAO.

As seen in the current schedule, not only did the “exterior backfill basement walls” start 7 days late but also its effort is expected to take 8 hours longer than originally planned. The 7-day late start and the extra effort consume the available 7 days of total float on the path, and the activities “exterior backfill basement walls” and “rough grade property” are now critical. The activities “install roof trusses” and “install roof decking” are no longer critical, because the delay in the backfill work created a day of total float for those activities. The start variance of “exterior backfill basement walls” is 7 days and the finish variance is expected to be 8 days. The effect of the backfill delay can clearly be seen in the variances of “rough grade property,” “form and pour driveway,” “finish excavate and pour garage floor,” and the finish milestone “framing complete.” Visually, the activity bars are far removed from their original baselined positions in the timeline.

In this situation, the general contractor has several possible solutions to get the construction schedule back on track:

- Adjust the working calendar. Forming and pouring the driveway could take place over the weekend. Alternatively, the excavators could work overtime to finish backfilling by the morning of March 28. Both options

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assume that resources are available for overtime work on short notice and that the project can afford the additional labor rate associated with overtime.

- Increase resources. Adding an additional worker to the backfill activity would reduce the activity's duration by 1 day. Again, this assumes that additional resources are available on short notice. The additional labor cost is unavoidable because of the additional work required, but this option leaves the labor cost at the normal rate.
- Perform activities concurrently. The general contractor could convince the excavator to begin grading the property a day earlier, when the backfilling is under way. However, because both activities require three excavators, as well as the same unique piece of equipment, resources will more than likely not be available.
- Do nothing and allow the framing to complete a day late. This assumes that the negative float of 1 day will be addressed at some point beyond framing, perhaps by adding resources during interior rough-in. However, this option affects many subsequent resource assignments such as plumbers, electricians, HVAC specialists, carpenters, and bricklayers. Each assignment will have to be rescheduled if the delay is carried beyond framing.

Figure 50 shows the impact of the general contractor's plan to get the program back on track by adding a resource to the backfill activity. This reduces the backfill activity by 1 day and places the "form and pour driveway" and "finish excavate and pour garage floor" activities back on their originally planned dates. The "framing complete" milestone is once again scheduled for April 2.

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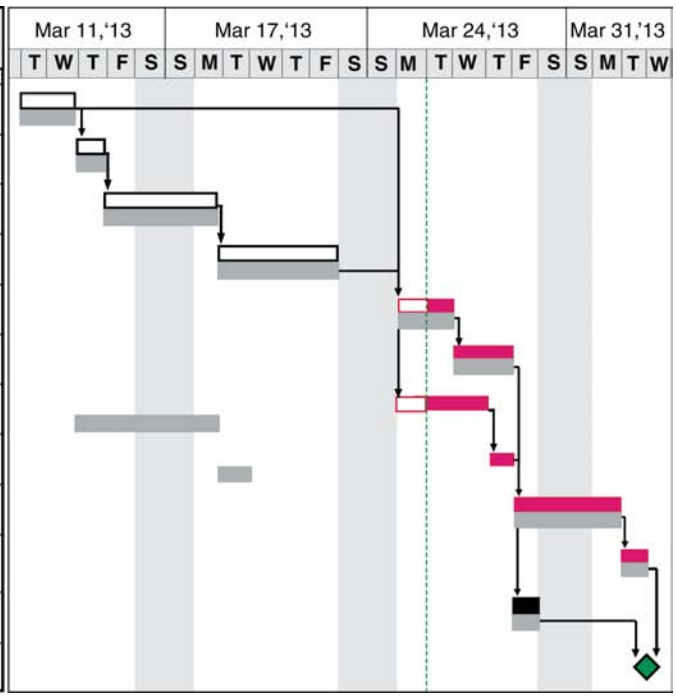
Figure 50: Updated Status and Proposed Plan Compared with Baseline

Activity name	Start	Actual start	Total float (in days)
Install first floor joists and decking	3-12-13	3-12-13	0
Install waterproofing on exterior basement walls	3-14-13	3-14-13	0
Finish excavate and pour basement floor	3-15-13	3-15-13	0
Frame first floor walls	3-19-13	3-19-13	0
Install roof trusses	3-25-13	3-25-13	0
Install roof decking	3-27-13	NA	0
Exterior backfill basement walls	3-25-13	3-25-13	0
Rough grade property	3-28-13	NA	0
Form and pour driveway	3-29-13	NA	0
Finish excavate and pour garage floor	4-2-13	NA	0
Rough-in framing inspection	3-29-13	NA	2
Framing complete	4-2-13	NA	0



Source: GAO.

The threshold for reporting variances will vary by project size, complexity, and risk. All stakeholders should agree on the threshold and it should be formally defined in a governing document. In particular, guidance should take into account the threshold for the number of days the activity is delayed as well as the available float. If a variance exceeds the threshold, it should be reported to management along with a detailed description that includes the cause and recommended corrective actions. Note that because level of effort activities support work activities, they will never show a variance.

Various schedule measures should be analyzed to identify and better understand the effect of schedule variances. Some examples of measures for comparing the current schedule to the baseline include the number of activities that

- have started early, on time, and late;
- have finished early, on time, and late;
- should but have not started;
- should but have not finished;
- should not but have started;

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- should not but have finished.

Trend Analysis

Trend analysis involves collecting schedule measure data during each status period and plotting them over time. Sustained variances in one direction should be documented to assess whether the project is heading toward a problem and to determine whether action is necessary. Trend analysis provides valuable information about how a program is performing. Knowing what has caused problems in the past can help determine whether they will continue. Typical schedule measure data that can help managers know what is happening in their programs are

- comparisons of the cumulative number of completed activities to the cumulative number of baselined activities planned to be completed;
- comparisons of the cumulative number of activities forecasted to be completed to the number of activities planned to be completed;
- available resources over time, highlighting overallocations;
- total float and schedule contingency tracked by status period;
- comparisons of actual, forecasted, and baselined completed activities.

The last plot is useful for identifying a potential bow wave of activities that will have to be completed at a higher rate than the rate at which activities have been previously completed. For example, if on average 15 detail activities have been accomplished per 2-week period yet forecasts imply that 30 detail activities need to be completed every 2 weeks to finish on time, the schedule is most likely unrealistic.

A measure known as the baseline execution index (BEI) is commonly used in baseline analyses. It is the ratio of the number of detail activities that were completed to the number of detail activities that should have been completed by the status date. A BEI of 1 indicates that the project is performing according to plan. A BEI less than 1 indicates that, in general, fewer activities are being completed than planned; a BEI greater than 1 indicates that, in general, more activities are being completed than planned.

The BEI is an objective measure of overall performance because it compares actual completions to planned completions. However, it is a summary measure—that is, it does not provide insight into why activities are not being completed according to plan or take into account the importance of their not being completed according to plan. For example, delayed activities that are on the critical path or on near-critical paths are given weight equal to delayed activities that have free float available.

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To provide additional insight, the BEI can be calculated against any group of activities—WBS level, resource group, or activity duration. Finally, note that the BEI will always equal 1 at the end of a project if, eventually, all activities are completed.

Strategies for Recovery and Acceleration

Table 1 summarizes common techniques schedulers and management teams use to recover schedule variances and, in general, accelerate the schedule. Schedule recovery is an effort by management to recover from the impact of interrupting events on the planned schedule. Acceleration refers to the technique of reducing the duration of the overall schedule. The focus for schedule recovery or acceleration should be on critical activities and, in particular, on long-duration critical activities. Because critical activities drive key milestone dates, the overall project duration will be reduced only by reducing the critical paths.

Table 1: Strategies for Schedule Recovery and Acceleration

Technique	Description	Side effects
Crashing	Add resources to time-dependent activities to complete work faster	Requires additional resources and will thus increase costs. May also reduce quality if activities are executed faster and with less experienced labor
Fast tracking	Involves reducing the sequential dependencies between activities to partial dependencies. That is, F–S logic is reduced to S–S logic or leads are introduced to force parallel work	Resources may become overallocated. Quality may also be reduced and risk introduced if activities ideally executed in sequence are now executed in parallel
Split long activities	Long activities may be split into shorter activities that can be worked in parallel	Resources may become overallocated
Review constraint and lag assumptions	Reassess assumptions related to forcing activities to begin on certain dates	If the original date constraint or lag is justified, the removal of the constraint or lag may not be realistic
Review duration estimates	Duration estimates should be revisited using progress records as actual effort is recorded on the project	
Add overtime and reduce vacations	Review nonworking periods and assign overtime work	Costs will increase over standard labor rates. As overtime increases, morale will decrease, eventually affecting the quality of the product negatively
Reduce scope	Decreasing scope reduces both duration and costs	Scope is the primary reason for performing the work. May not be able to delete some requirements
Schedule contingencies	Allocate contingency to absorb delay in accordance with identified risk mitigation plans	Using contingency too early in a project will reduce the likelihood of the program's completing on time, particularly if the reason for a delay was not a risk that was previously identified and quantified

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Regardless of what combination of methods is used for acceleration or recovery of variances, the schedule should be archived before the change. After the schedule is modified, the techniques used should be documented and the critical path recalculated and assessed for reasonableness.

Best Practices Checklist: Maintaining a Baseline Schedule

- A baseline schedule
  - is set promptly after the program begins;
  - is the basis for measuring performance;
  - represents the original configuration of the program plan and signifies the consensus of all stakeholders regarding the required sequence of events, resource assignments, and acceptable dates for key deliverables;
  - is compared to the current schedule to track variances from the plan.
- There are plans to archive the as-built version of the schedule that
  - represent the plan as executed to completion;
  - can be compared to the original plan for an assessment of lessons learned;
  - become a valuable basis of estimate input for schedule estimates of future analogous projects;
  - become the basis for creating and validating fragnets where possible.
- A baseline schedule document is a single document that
  - defines the organization of the IMS;
  - describes the logic of the network;
  - describes the basic approach to managing resources;
  - provides a basis for all parameters used to calculate dates;
  - describes the general approach to the project;
  - defines how to use the schedule file;
  - describes the schedule's unique features;
  - describes the schedule change management process;
  - contains a dictionary of acronyms and custom fields;
  - gives an overview of the assumptions and ground rules, including justification for
    - calendars,
    - lags,
    - date constraints,
    - long activity durations, and
    - calendars and working times;

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  - describes the use and assignments of resources within the schedule at an appropriate level of detail;
  - describes the critical risks prioritized in a schedule risk analysis as well as schedule contingency;
  - discusses the derivation of the critical paths, longest path, and total float for the program;
  - is considered a living document that reflects updates to the baseline schedule.
- Changes to the baseline schedule are reviewed and approved according to the change control process.
- Schedule variances that exceed predetermined thresholds are reported to management, along with the cause and any corrective actions.
- Negative schedule variances should be investigated to see if the associated effort is on the critical path.
- Schedule measures, such as the number of activities that have started or finished early, on time, or later than planned, are analyzed for the effect of any variances.
- Trend analysis is conducted periodically to examine measures such as decreasing float and schedule contingency erosion.
- The focus of any schedule recovery or acceleration techniques is on critical activities.

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Four Characteristics of a Reliable Schedule

Our research has identified four characteristics of a high-quality, reliable schedule: they are comprehensive, well-constructed, credible, and controlled.

A comprehensive schedule includes all activities for both the government and its contractors necessary to accomplish a project's objectives as defined in the project's WBS. The schedule includes the labor, materials, and overhead needed to do the work and depicts when those resources are needed and when they will be available. It realistically reflects how long each activity will take and allows for discrete progress measurement.

A schedule is well-constructed if all its activities are logically sequenced with the most straightforward logic possible. Unusual or complicated logic techniques are used judiciously and justified in the schedule documentation. The schedule's critical path represents a true model of the activities that drive the project's earliest completion date and total float accurately depicts schedule flexibility.

A schedule that is credible is horizontally traceable—that is, it reflects the order of events necessary to achieve aggregated products or outcomes. It is also vertically traceable: activities in varying levels of the schedule map to one another and key dates presented to management in periodic briefings are in sync with the schedule. Data about risks and opportunities are used to predict a level of confidence in meeting the project's completion date. The level of necessary schedule contingency and high-priority risks and opportunities are identified by conducting a robust schedule risk analysis.

Finally, a schedule is controlled if it is updated periodically by trained schedulers using actual progress and logic to realistically forecast dates for program activities. It is compared against a designated baseline schedule to measure, monitor, and report the project's progress. The baseline schedule is accompanied by a baseline document that explains the overall approach to the project, defines ground rules and assumptions, and describes the unique features of the schedule. The baseline schedule and current schedule are subject to a configuration management control process.

Table 2 shows how the 10 scheduling best practices can be mapped to the four characteristics of a high-quality, reliable schedule.

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Table 2: The Four Characteristics of a Reliable Schedule

Schedule characteristic	Schedule best practice
Comprehensive, reflecting • all activities as defined in the project's WBS • the labor, materials, and overhead needed to do the work and whether those resources will be available when needed • how long each activity will take, allowing for discrete progress measurement with specific start and finish dates	1 Capturing all activities 3 Assigning Resources to all activities 4 Establishing the durations of all activities
Well constructed, with • all activities logically sequenced with predecessor and successor logic • limited amounts of unusual or complicated logic techniques that are justified in the schedule documentation. • a critical path that determines which activities drive the project's earliest completion date • total float that accurately determines the schedule's flexibility	2 Sequencing all activities 6 Confirming that the critical path is valid 7 Ensuring reasonable total float
Credible, reflecting • the order of events necessary to achieve aggregated products or outcomes • varying levels of activities, supporting activities, and subtasks • key dates that can be used to present status updates to management • a level of confidence in meeting a project's completion date based on data about risks and opportunities for the project. • necessary schedule contingency and high priority risks based on conducting a robust schedule risk analysis	5 Verifying that the schedule is traceable horizontally and vertically 8 Conducting a schedule risk analysis
Controlled, being • updated periodically by schedulers trained in critical path method scheduling • statused using actual progress and logic to realistically forecast dates for program activities • compared against a documented baseline schedule to determine variances from the plan • accompanied by a corresponding baseline document that explains the overall approach to the project, defines assumptions, and describes unique features of the schedule • subject to a configuration management control process	9 Updating the schedule with actual progress and logic 10 Maintaining a baseline schedule

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Appendix I: An Auditor's Key Questions and Documents

Best Practice 1: Capturing All Activities

Key Questions

1. Is there an IMS for managing the entire program (not just a block, increment, or prime contractor)? Is the schedule defined at an appropriate level to ensure effective management?
2. Is the IMS maintained in scheduling software and linked to external detailed subproject schedules? Do the government program management office and contractors have different scheduling software systems? If so, how is integrity preserved and verified when converting the schedule?
3. Does the IMS include government, contractor, and applicable subcontractor effort?
4. Does the schedule reflect the program WBS and does the WBS enable the tracking of key deliverables? Does every activity trace to an appropriate WBS element, and do the activities define how the deliverables will be produced? Is there a WBS dictionary?
5. Are key milestones identified and are they consistent with the contract dates and other key dates established by management in the baseline schedule?
6. Are clear start and finish milestones present in the schedule? Are there too many milestones in relation to detail activities?
7. Are all activities mapped to the contract statement of work (SOW) or statement of objectives (SOO) to ensure that all effort is accounted for in the schedule? Are activities within the schedule easily traceable to key documents and other information through activity or task codes?
8. Are activity names unique and descriptive? Are activities phrased in verb-noun combinations (for example, "develop documentation")? Are milestones named with verb-noun or noun-verb combinations (for example, "start project" or "project finished")?
9. Are level-of-effort activities clearly marked? Are LOE activity durations determined by the activities they support?
10. Does the schedule include risk mitigation activities?

Key Documentation

1. Work breakdown structure (WBS), statement of work or objectives (SOW or SOO), and mission requirements
2. SOW or SOO crosswalk to the schedule WBS
3. Contractor WBS to program WBS crosswalk
4. Schedule custom fields and activity codes dictionary and LOE field identification
5. Activity codes used to organize and filter the activities into categories as necessary to confirm a complete scope of work

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6. Engineering plans used to define activities, such as systems engineering plan, software development plan, risk management plan, and master test plan.
7. Systems engineering life cycle, system development life cycle, or other required life cycle documentation
8. Enterprise architecture documentation for software programs

Likely Effects If Criteria Are Not Fully Met

1. If activities are missing from the schedule, then other best practices will not be met. If all necessary activities are not accounted for, it is uncertain whether all activities are scheduled in the correct order, resources are properly allocated, missing activities will appear on the critical path, or a schedule risk analysis can account for all risk.
2. Failing to include all work for all deliverables, regardless of whether the deliverables are the responsibility of the government or contractor, can lead to project members' difficulties because of an incomplete understanding of the plan and its progress toward a successful conclusion.
3. If the project schedule does not fully and accurately reflect the project, it will not be an appropriate basis for analyzing or measuring technical work accomplished and may result in unreliable completion dates, time extension requests, and delays.
4. If government work is not captured in the IMS, the program manager will be less able to plan all the work and minimize the risk of government-caused delays.
5. Because the schedule is used for coordination, missing elements will hinder coordination efforts, increasing the likelihood of disruption and delays.
6. If the schedule is not sufficiently detail planned, then opportunities for process improvement (for example, identifying redundant activities), what-if analysis, and risk mitigation will be missed.
7. LOE activities can interfere with the critical path unless they are clearly marked and represented as summary or hammock activities designed for the purpose.
8. Too many milestones in the schedule can mask the activities necessary to achieve key milestones and can prevent the proper recording of actual progress.
9. Schedules that are defined at too high a level may disguise risk that is inherent in lower-level activities. Conversely, schedules that have too much detail make it difficult to manage progress.
10. Unless the schedule is aligned to the program WBS, management cannot ensure that the total scope of work is accounted for within the schedule.

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11. Repetitive naming of activities makes communication difficult between teams, particularly between team members who are responsible for updating and integrating multiple schedules.

Best Practice 2: Sequencing All Activities

Key Questions

1. Have the activities and logical relationships been determined by those executing the project?
2. Are the majority of the relationships within the detailed schedules finish-to-start?
3. Are there any dangling predecessors or successors?
   a. Does each activity (except the start milestone) have an F–S or S–S predecessor that drives its start date?
   b. Does each activity (except the finish milestone and deliverables that leave the project without subsequent impact on the project) have an F–S or F–F successor that it drives?
4. Do summary activities have predecessor or successor links?
5. Do activities have start-to-finish links?
6. How much convergence (that is, several parallel activities converging at one major event) is there in the schedule?
7. Does the schedule contain date constraints other than "as soon as possible"? Is each one justified in the schedule documentation?
8. Is the work of suppliers, government offices or agencies, or subcontractors represented in the schedule as an activity so that risk can be applied rather than representing the "promise date" as a date-constrained milestone?
9. Are lags or leads specified between the activities? Can these be more accurately characterized by improving logic or adding activity detail?

Key Documentation

1. Justification for using hard and soft date constraints instead of activities' duration and logic
2. Justification for lags and leads instead of activities' duration and logic
3. Justification for any activity that has no F–S or S–S predecessor or no F–S or F–F successor

Likely Effects If Criteria Are Not Fully Met

1. The logical sequencing of events is directly related to float calculations and the critical path. If the schedule is missing dependencies or if activities are linked incorrectly, float estimates will be miscalculated. Incorrect float estimates may result in an invalid

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critical path and, thus, will not be reliable indicators of where resources can be shifted to support delayed critical activities.

2. That all interdependencies between activities are identified is necessary for the schedule to properly calculate dates and predict changes in the future. Without the right linkages, activities that slip early in the schedule do not transmit delays to activities that should depend on them. When this happens, the schedule will not provide a sufficient basis for understanding the program as a whole, and users of the schedule will lack confidence in the dates and the critical path. Finally, when activities are not correctly linked, the program cannot use the IMS to identify disconnects or hidden opportunities and cannot otherwise promote efficiency and accuracy or control the program by comparing actual to planned progress.
3. Logical sequencing promotes a more realistic workflow. If missing, project team members can misunderstand one another, especially regarding receivables and deliverables.
4. The presence of "dangling activities" reduces the credibility of the calculated activity start and finish dates and the identity of the critical paths. The slip or elongation of an activity that has no logical successor will not reflect its effect on the scheduled start dates of successor activities.
   a. If an activity—other than the start milestone—does not have an F–S or S–S predecessor that drives its start date, the activity will start earlier if its duration is projected to be longer than originally believed. An earlier start may be illogical.
   b. If an activity—other than the finish milestone or deliverable that leaves the project—does not drive a successor by an F–S or F–F link, the implications of its running late or long are not passed on to any successor activity.
5. The ability of a schedule to forecast start and finish dates of activities and key events is directly related to the complexity and completeness of the schedule network. Unless complete network logic is established, the schedule cannot predict impacts on the project's planned finish date from, among other things, misallocated resources, delayed activities, external events, and unrealistic deadlines.
6. Because a logic relationship dictates the effect of an on-time, delayed, or accelerated activity on following activities, any missing logic relationship is potentially damaging to the entire network.
7. Path convergence issues can represent an unrealistic plan by implying that a large number of activities must be finished at the same time before a major event can occur as planned. An excess number of parallel relationships can indicate an overly aggressive or unrealistic schedule.

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8. Hard date constraints that restrict activities to starting or finishing on a specific date must be justified by referring to some controlling event outside the schedule. Date constraints prevent activities from responding dynamically to network logic, including actual progress and availability of resources. They can seriously affect float calculations and the identification or continuity of the critical path and can mask actual progress or delays in the schedule.
9. Hard and soft constraints interfere with the results of a schedule risk analysis because they prevent activity dates within the schedule from dynamically responding to changes in predecessor dates.
10. A customer-mandated date is not a legitimate reason to constrain an activity. A schedule is intended to be a dynamic, pro-active planning and risk mitigation tool that models the project and can be used to track actual progress toward important project milestones. Schedules with constrained dates can portray an artificial or unrealistic view of the project plan.
11. Constraints should be used only when necessary and only if their justification is documented because they override network logic and restrict how planned dates respond to actual accomplished effort or resource availability. A large number of activities with constraints is typically a substitute for logic and can mean that the schedule is not well planned and may not be feasible.
12. SNLT and FNLT constraints prevent activities from starting or finishing later than planned, essentially restricting the ability of any predecessor delays to affect their start and finish dates.
13. Applying constraints to represent the availability of resources requires constant manual upkeep of the schedule.
14. Mandatory start and finish constraints are the most rigid of all constraints because they do not allow the activity either to take advantage of time savings by predecessor activities or to slip in response to delayed predecessors or longer-than-scheduled durations.
15. The time to produce an external product should be represented by a reference or schedule visibility activity rather than a constrained milestone representing receipt of the product. By modeling vendor or contractor production as an activity, the program office can track the contractor's high-level progress and apply risk to the external production activity.
16. Lags must be justified because they may represent work or a delay that may be variable while the lag is static. Lags should not be used to represent activities because they cannot be easily monitored or included in the risk assessment and do not take resources. Activities represented by lags are not, in fact, risk free.

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17. Constantly updating lags manually defeats the purpose of a dynamic schedule and makes it particularly prone to error.
18. The use of a lag with F–S logic is generally not good practice because it is generally not necessary. In such cases, every effort should be made to break activities into smaller tasks and to identify realistic predecessors and successors so that logic interface points are clearly available for needed dependency assignments.
19. Leads are generally not valid. As negative lags, leads imply the unusual measurement of negative time and exact foresight about future events.
20. Lags are also often used as buffers for risk between two activities, but this practice should be discouraged because the lags persist even as the actual intended buffer is used up.

Best Practice 3: Assigning Resources to All Activities

Key Questions

1. What resources are specified and assigned to the activities? At what level of detail are resources specified (for example, labor categories, organizations, or individual names)?
2. Are significant material and equipment resources captured in the schedule?
3. Do the resources have logical resource calendars?
4. How were resource estimates developed for each activity?
5. Has analysis been performed to ensure that resources are sufficient and available in each work period when needed?
   a. Are there potential difficulties in obtaining scarce resources to accomplish the work?
   b. Are there work periods for which more resources are required than are available? What is the plan for resolving resource deficiencies?
6. Has resource leveling been performed?
7. To what extent are the resource estimates in the schedule consistent with those in the project cost estimate?

Key Documentation

1. Basis of estimates for resource assumptions should align with resource estimates within the cost estimates.
2. A resource allocation planning document should define resource profiles and tables for unique resources derived from the schedule.
3. Resource output from scheduling software across all project schedules should be reported. This highlights the problem of

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assigning resources to several schedules in parallel. It also catches any issues with the resource leveling assumptions that the software is using and the use of "placeholder" resource names.

Likely Effects If Criteria Are Not Fully Met

1. Information on resource needs and availability in each work period assists the program office in forecasting the likelihood that activities will be completed as scheduled. If the current schedule does not allow insight into current or projected allocation of resources, then the risk of the program's slipping is significantly increased. Overallocated resources result in inefficiency (for example, staff are less productive because of extended overtime) or project delay from unavailable resources.
2. Resources must be considered when creating a schedule because their availability directly affects an activity's duration.
3. A schedule without resources implies an unlimited number of resources and their unlimited availability.
4. If there is no justification for allocating and assigning resources, the schedule will convey a false level of accuracy.
5. Bow waves in forecasts of resource assignments represent the need for large amounts of resources near the end of work streams to finish deferred or delayed work on time. Often the number of resources and funding required at the peak of the bow wave are unrealistic.
6. If resource leveling causes enormous delays in the project finish date—for example, by many months or years—then the original resource assumptions, network logic, or activity durations must be examined for pragmatism.
7. Automatic resource leveling can lead to inefficient output by delaying activities if only partial resources are available and preventing activities from being partially accomplished while waiting for the full complement of resources to become available.
8. Incorrect resource assumptions (usually in the form of unwarranted optimism) will lend unreasonable credence to a resource-leveled schedule, and the resulting leveled schedule will convey a false sense of precision and confidence to senior decision makers.
9. A schedule that has not reviewed and resolved resource utilization issues is not credible.
10. If the baseline schedule does not identify the planned resources, it cannot be used to make important management decisions, such as reallocating resources from activities with significant float to critical activities that are behind schedule.
11. If the schedule does not have resource assignments, management's ability to monitor crew productivity, allocate idle resources, monitor resource-constrained activities, and level resources across activities is severely limited.

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Best Practice 4: Establishing Durations for All Activities

Key Questions

1. Were durations determined from work to be done and realistic assumptions about available resources, productivity, normal interferences and distractions, and reliance on others?
2. For a detailed schedule, are durations short enough to be consistent with the needs of effective planning and project execution? Are durations no more than two reporting periods for effective statusing and progress reporting of near-term work? Are activity durations too short?
3. Are activities long in duration because of LOE or rolling wave planning?
4. Were durations estimated by the person responsible for the activities or reviewed with experts who have experience with similar types of work?
5. Was the project duration determined by some target or mandated date?
6. Are durations based on appropriate calendars? Do any specific conditions necessitate special calendars, and are they addressed (for example, religious holidays, nonwork periods for climate, shift work, unavailability of resources)? Are activity durations assigned inconsistent time units?

Key Documentation

1. How durations of work activities were estimated is documented at the appropriate level of detail. For instance, the basis of estimate includes the assumptions made to justify the durations assumed for the cost. These should be consistent with the durations at the same level of detail.
2. Documentation justifies nonstandard working calendars.
3. Documentation justifies excessively long durations, including the identification of LOE activities and how they were scheduled.

Likely Effects If Criteria Are Not Fully Met

1. If activities are too long, the schedule may not have enough detail for effective progress measurement and reporting.
2. If activities are too short, the schedule may be too detailed. This may lead to excessive work in maintaining the logic, updating the status of activities, and managing the many short-duration activities.
3. When durations are not based on the effort required to complete an activity, the resources available, resource efficiency, and other factors

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such as previous experience on similar activities, then there is little confidence in meeting the target deliverable date.
4. Schedules determined by imposed target completion dates rather than work and logic are often infeasible.
5. Durations estimated under optimal or "success-oriented" conditions will produce unrealistic project delivery dates and unreliable critical paths and could mask program or project risks.
6. Proper use of resource and task calendars will usually preclude the need for soft constraints in schedules. But improperly defined task or resource calendars will incorrectly represent the forecasted start, finish, and durations of planned activities.
7. The default calendar in a schedule software package rarely has appropriate national holidays defined as exceptions and will not have specific blackout periods or other project-specific exceptions defined.
8. Schedules will incorrectly represent the forecasted start, finish, and durations of planned work if resources are assigned to incorrect calendars. Ensuring realistic calendars will provide for more accurate dates and may reveal opportunities to advance the work.

Best Practice 5: Verifying That the Schedule Is Traceable Horizontally and Vertically

Key Questions

1. Is all logic in place and has the technical content of the schedule been validated?
2. Are major hand-offs and deliverables easily identified in the schedule? How are major hand-offs and deliverables negotiated and monitored?
3. Does the schedule have fields that record the responsible givers and receivers?
4. Are the key dates consistent between lower-level detailed working schedules and higher-level summary schedules? Do all lower-level activities roll up into higher WBS levels?
5. Do major milestones map between the schedule and management-level briefing charts?

Key Documentation

1. All representations of the schedule are given as of a specific time. These may include different levels of the same schedule used in presentations as well as schedule representation using different

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platforms (scheduling or presentation packages) for different audiences.
2. The integration between summary, intermediate, and detailed schedules is demonstrated.

Likely Effects If Criteria Are Not Fully Met

1. If the schedule is not horizontally traceable, there may be little confidence in the calculated dates or critical paths. Schedules that are not horizontally integrated may not depict relationships between different program elements and product handoffs. Any logic errors between summary, intermediate, and detailed schedules will cause inconsistent dates between schedules and will cause different expectations between management and activity owners.
2. Unless the schedule is horizontally traceable, activities whose durations are greatly extended will have no effect on key milestones.
3. Schedules that are not horizontally integrated may not depict relationships between different program elements and product hand-offs. When this happens, hand-offs of project subcomponents cannot be fully traced to the end product, leading to less effective project management.
4. Vertical traceability provides assurance that the representation of the schedule to different audiences is consistent and accurate. Without vertical traceability, there may be little confidence that all consumers of the schedule are getting the same correct schedule information.
5. Unless the schedule is vertically traceable, lower-level schedules will not be consistent with upper-level schedule milestones, affecting the integrity of the entire schedule and the ability of different teams to work to the same schedule expectations.
6. Without horizontal and vertical traceability, there is no valid critical path or computation of float.

Best Practice 6: Confirming That the Critical Path Is Valid

Key Questions

1. Is the critical path, or longest path in the presence of late-date constraints, calculated by the scheduling software valid?
   a. Are any activities in the schedule missing logic or constrained without justification? Are these issues resulting in an unreliable critical path?
   b. Is the critical path a continuous path from the status date to the major completion milestones?

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c. Does the critical path start with a constraint so that other activities are unimportant in driving the milestone date? If so, is there justification for that constraint?
d. Does the critical path include LOE activities? Is the critical path driven by activities of unusually long duration?
e. Is the critical path driven in any way by lags or leads?

2. Does management use the critical path to focus on activities that will have detrimental effects on key project milestones and deliveries if they slip?
3. Does the scheduling software identify activities that drive the dates of key deliveries and milestones?
4. If there are several important milestones, are the critical paths to them clearly identified, continuous, and free of constraints, LOE activities, leads, and lags?

Key Documentation

1. Important program deliverables or milestones for which critical paths should be established are identified.
2. Printouts of the logic diagram indicate the longest paths to the important milestones, as well as critical paths based on total float to all major milestones.
3. Near-critical paths are identified.

Likely Effects If Criteria Are Not Fully Met

1. Successfully identifying the critical path relies on capturing all activities (Best Practice 1), properly sequencing activities (Best Practice 2), horizontal traceability (Best Practice 5), the reasonableness of float (Best Practice 7), accurate status updates (Best Practice 9), and—if there are resource limitations—assigning resources (Best Practice 3). Unless the schedule is fully horizontally traceable, the effects of slipped activities on successor activities cannot be determined. If the schedule is missing dependencies or if activities are not linked correctly, float estimates will be miscalculated. Incorrect float estimates will result in an invalid critical path and will hinder management's ability to allocate resources from noncritical activities to those that must be completed on time.
2. Until the schedule can produce a true critical path, the program office will not be able to provide reliable timeline estimates or identify when problems or changes may occur and their effect on downstream work.
3. LOE activities should not drive the schedule. LOE and repetitive activities support effort, and their durations are determined by detail activities. For example, a project's length is not determined by biweekly meetings or program management. If the schedule has discrete durations and driving logic for LOE activities, it will potentially confuse the identification of, and deflect program attention away from,

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the critical path. If LOE is critical, management has no indication of which activities can slip and which will respond positively to additional resources to reduce the risk of finishing late.

4. Without a valid critical path, management cannot focus on activities that will have detrimental effects on the key project milestones and deliveries if they slip.
5. Risk in activities on critical paths should be examined and mitigated because it has the potential to delay key program deliveries and milestones.
6. The review and analysis of near-critical paths is important because their activities are likely to overtake the existing critical path and drive the schedule.

Best Practice 7: Ensuring Reasonable Total Float

Key Questions

1. Are the total float values the scheduling software calculates reasonable and do they accurately reflect true schedule flexibility?
2. Are excessive values of total float being driven by activities that are missing logic?
3. Is total float calculated to the main deliveries and milestones as well as to the project's completion?
4. Is total float monitored? Does management have a plan to mitigate negative total float?
5. Does management rely on free float to level resources or reassign resources to assist critical activities?

Key Documentation

The project team can use a list of activities sorted by their total float values to determine whether the total float values correctly reflect flexibility in the project schedule.

Likely Effects If Criteria Are Not Fully Met

1. If the schedule is missing activities or dependencies or links activities incorrectly, float estimates will not be accurate. Incorrect float estimates may result in an invalid critical path and an inaccurate assessment of project completion dates. In addition, inaccurate values of total float falsely depict true project status, which could lead to decisions that may jeopardize the project. For example, if activities are not linked correctly to successors, total float will be greater than it should be.
2. Because the critical path is directly related to the logical sequencing of events and float calculations, if the schedule is missing dependencies

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or if activities are incorrectly linked, float estimates will be miscalculated, resulting in an invalid critical path.

3. Without accurate values of total float, it cannot be used to identify activities that could be permitted to slip and thus release and reallocate resources to activities that require more resources to be completed on time.
4. Negative float indicates that not enough time has been scheduled for the activity and is usually caused by activities taking longer or starting later than planned, making target dates infeasible. The project may have to take some corrective action or the negative float may act as a lien against or threat to the project end date.
5. Too little float built into the schedule may indicate insufficient time to recover from delay without slipping the program's completion date.

Best Practice 8: Conducting a Schedule Risk Analysis

Key Questions

1. Was an SRA performed to determine the confidence level in achieving the program schedule and other key dates?
   a. Was the schedule checked to ensure that it meets best practices before the simulation was conducted?
   b. Are there data fields within the schedule for risk analysis such as low, most likely, and high durations?
   c. Were uncertainties in activity durations statistically correlated to one another?
   d. How much schedule contingency was selected and what is the probability of meeting the completion date?
   e. Did the SRA identify activities during the simulation that most often ended up on the critical path, so that near-critical path activities can be closely monitored?
2. Was a risk register used as an input to schedule development?
   a. Was the risk register used in identifying the risk factors potentially driving the schedule before the SRA was conducted?
   b. Once the SRA was conducted, were risks prioritized by probability and magnitude of impact?
3. Are the SRA data, assumptions, and methodology available and documented?

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4. Have the risk inputs been validated? Are the ranges reasonable and based on information gathered from knowledgeable sources? Is there evidence of bias in the risk data?
5. How is the use of schedule contingency controlled and authorized?

Key Documentation

1. A risk register with prioritized risks should be available.
2. SRA documentation should include assumptions, methodology, data, data normalization techniques, and findings.
3. If applicable, people should be listed who were interviewed or included in risk interviews, including their organization, position, or expertise.
4. The schedule risk analysis file is available.

Likely Effects If Criteria Are Not Fully Met

1. If a schedule risk analysis is not conducted, the following cannot be determined:
   a. the likelihood of the project's completion date,
   b. how much schedule risk contingency is needed to provide an acceptable level of certainty for completion by a specific date,
   c. risks most likely to delay the project,
   d. how much contingency reserve each risk requires, and
   e. the paths or activities that are most likely to delay the project.
2. Because activity durations are uncertain, the identity of the true critical path is also unknown unless a schedule risk analysis has been performed. An SRA can identify the paths that are most likely to become critical as the project progresses so that risk mitigation can lessen the effect of any delays.
3. Unless a statistical simulation is run, calculating the completion date from schedule logic and the most likely duration distributions will tend to underestimate the program's overall critical path duration.
4. If the schedule risk analysis is to be credible, the program must have a quality schedule that reflects reliable logic and clearly identifies the critical path. If the schedule does not follow best practices, confidence in the SRA results will be lacking. Without this analysis, the program office cannot sufficiently understand the level of confidence in meeting the program's completion date and identifying reserves for contingencies.
5. If the program does not have sufficient schedule reserve, then risk mitigation actions and schedule issues from unforeseen events may not be managed without a schedule delay.
6. If the task durations are not correlated to one another, the uncertainty on the critical path duration will be underestimated.

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Best Practice 9: Updating the Schedule Using Logic and Progress

Key Questions

1. Is the schedule progress recorded periodically? Has the schedule been updated recently as planned? Is the status date recorded? Is at least one in-progress activity critical?
2. Do any activities have start or finish dates in the past without actual start or finish dates? Are there any activities with actual start or finish dates in the future?
3. Is responsibility for changing or statusing the schedule assigned to someone who has the proper training and experience in CPM scheduling?
4. Is there a list of logic changes that were made to the schedule during the update? Are there any comments in the schedule activities to document logic changes?
5. Were any activities started or completed out of sequence? If so, was the logic retained, or did the scheduler use progress override?
6. A schedule narrative accompanies each status update and includes
   a. the status of key milestone dates, including the program finish date;
   b. the status of key hand-offs or giver/receiver dates;
   c. explanations for any changes in key dates;
   d. changes in network logic, including lags, date constraints, and relationship logic and their effect on the schedule timeframe;
   e. a description of the critical paths, near-critical paths, and longest paths along with a comparison to the previous period's paths; and
   f. any significant scheduling software options that changed between update periods, such as the criticality threshold for total float, progress override versus retained logic, or whether or not resource assignments are progressed along with duration.
7. Is the schedule structure examined after each update to ensure that no logic is missing, constraints are necessary, and no activities impede the ability of the schedule to dynamically forecast dates?

Key Documentation

1. The schedule shows actual and planned dates, remaining duration for in-process activities, and the status date.
2. Copies of project management review (PMR) briefings to verify whether schedule status is discussed and consistent with the schedule.

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Likely Effects If Criteria Are Not Fully Met

1. If the schedule is not continually monitored to determine when forecasted completion dates differ from planned dates, then it cannot be used to determine whether schedule variances will affect downstream work.
2. Maintaining the integrity of the schedule logic is not only necessary to reflect true status but is also required before conducting a schedule risk analysis. If the schedule has not been updated, then it is impossible to tell what activities have been completed, are in progress, are late, and are planned to start on time.
3. A schedule that has not been updated will not reflect what is actually occurring on the project and hence may have inaccurate completion dates and critical paths. When this is the case, management cannot use the schedule to monitor progress and make decisions regarding risk mitigation, resource allocations, and so on.
4. Unless a status date is provided, the schedule cannot be used to reliably convey effort spent and remaining.
5. A schedule with progress remaining out of sequence may have the wrong logic in place and, hence, inaccurate critical paths and completion dates.
6. If unfinished work remains in the past, the schedule no longer represents a realistic plan to complete the project, and team members will lose confidence in the model.
7. At least one in-progress activity is critical. If not, it is most likely that date constraints or external dependencies are separating subsequent from in-progress activities. Such breaks in the critical or longest path represent weak or incomplete logic, causing a lack of credibility in the identity of the path and the schedule dates.
8. Without a documented, consistently applied schedule change control process, project staff might continually revise the schedule to match performance, hindering the project manager's insight into the true performance of the project. Good documentation helps with analyzing changes in the program schedule and identifying the reasons for variances between estimates and actual results, thereby contributing to the collection of cost, schedule, and technical data that can be used to support future estimates.
9. Unless the schedule is kept updated, trend reports and analyses that highlight problems will not be useful in mitigating future delays.
10. Unless progress records are archived, historical data necessary for resource, work, and productivity assumptions for future analogous projects will not be available. If sufficient attention is paid to recording the way work is actually performed, the resulting archived data will help improve the accuracy and quality control of future similar projects.

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Best Practice 10: Maintaining a Baseline Schedule

Key Questions

1. Is the baseline schedule the basis for measuring performance?
2. Does a baseline schedule document exist? Does the document
   a. describe the general approach to the project, define how to use the electronic schedule file, and describe the schedule's unique features?
   b. describe the schedule change management process?
   c. contain a dictionary of abbreviations, acronyms and custom fields?
   d. provide an overview of the assumptions and ground rules, including justification for calendars and any lags, constraints, or long activity durations?
   e. describe the use of resources within the schedule?
   f. describe the critical risks prioritized in a schedule risk analysis as well as schedule contingency?
   g. discuss the derivation of the critical paths and longest path and justify excessive total float?
3. Are changes to the baseline schedule reviewed and approved according to the schedule change control process?
4. Is trend analysis performed, such as monitoring start and finish dates, available float, and available schedule contingency?
5. Is there a large bow wave of work to the right of the status date that is unrealistic?

Key Documentation

1. The designated baseline schedule is available.
2. The schedule change control process is described.
3. The current schedule change control log is available.
4. The baseline schedule is documented.

Likely Effects If Criteria Are Not Fully Met

1. Without a formally established baseline schedule to measure performance against, management cannot identify or mitigate the effect of unfavorable performance.
2. Good documentation helps with analyzing changes in the program schedule and identifying the reasons for variances between estimates and actual results, thereby contributing to the collection of cost, schedule, and technical data that can be used to support future estimates.
3. Thorough documentation is essential for validating and defending a baseline schedule. A well-documented schedule can convincingly

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argue for a schedule's validity and can help answer decision makers' and oversight groups' probing questions. A well-documented schedule is essential if an effective independent review is to ensure that it is valid and credible.

4. If changes are not controlled and fully documented, performance cannot be accurately measured against the original plan. Undocumented or unapproved changes will hamper performance measurement and may result in inaccurate variance reporting, inconsistent stakeholder versions of the plan, and unreliable schedule data.
5. Without a schedule change control process, traceability for all status updates will be unreliable, and there will be no guarantee that stakeholders are using the same version of the schedule.
6. Unless schedule variances are monitored, management will not be able to reliably determine whether forecasted completion dates differ from the planned dates.
7. Without trend analysis, management will lack valuable information about how a program is performing. Knowing what has caused problems in the past can help determine whether they will continue in the future.

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Appendix II: The Forward and Backward Pass

Early and late activity dates are determined by the logical sequence of effort that planners lay out. Network logic will calculate activity dates that define both when an activity may start and finish and when an activity must start and finish in order to meet a specified program completion date.

Suppose house construction and exterior finishing have been completed, and a certificate of occupancy (CO) has been issued. Several activities remain before the owner can occupy the house; specifically, utility systems must be started up and tested. Workers must

- set the electricity meter,
- start up and test the electrical system,
- set the gas meter,
- start up and test the furnace and air conditioner,
- set the water meter, and
- start up and test the plumbing fixtures.

Once these activities are completed, then the start-up and testing phase will be completed and the owner can occupy the house.

These activities must happen in a specified order:

- The electricity, gas, and water meters cannot be set until the CO is issued.
- The electrical system cannot be tested until the meter is set.
- The furnace and air conditioner cannot be tested until the gas and electricity meters are set.
- The plumbing fixtures cannot be tested until the gas and water meters are set.
- The start-up and test phase is complete when the electrical system, furnace, air conditioner, and plumbing fixtures are tested.

Table 3 shows the expected durations of each activity, given the estimated resources.

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Table 3: Expected Durations and Estimated Resources

Activity	Resource name	Resource units	Work hours	Duration in days
Set electricity meter	Electrician	2	16	1
	Electrical service technician	1	8	
Start up and test electrical system	Electrician	1	16	2
Set gas meter	Gas service technician	2	16	1
Start up and test furnace and air conditioner	HVAC technician	1	8	1
Set water meter	Water service technician	2	16	1
Start up and test plumbing fixtures	Plumber	2	32	2

Source: GAO.

Assuming the CO is attained on Monday, June 24, the electricity, gas, and water meters can be set the next day. Then, assuming that all succeeding activities are related by finish-to-start relationships, the start-up and testing network will appear as in figure 51.

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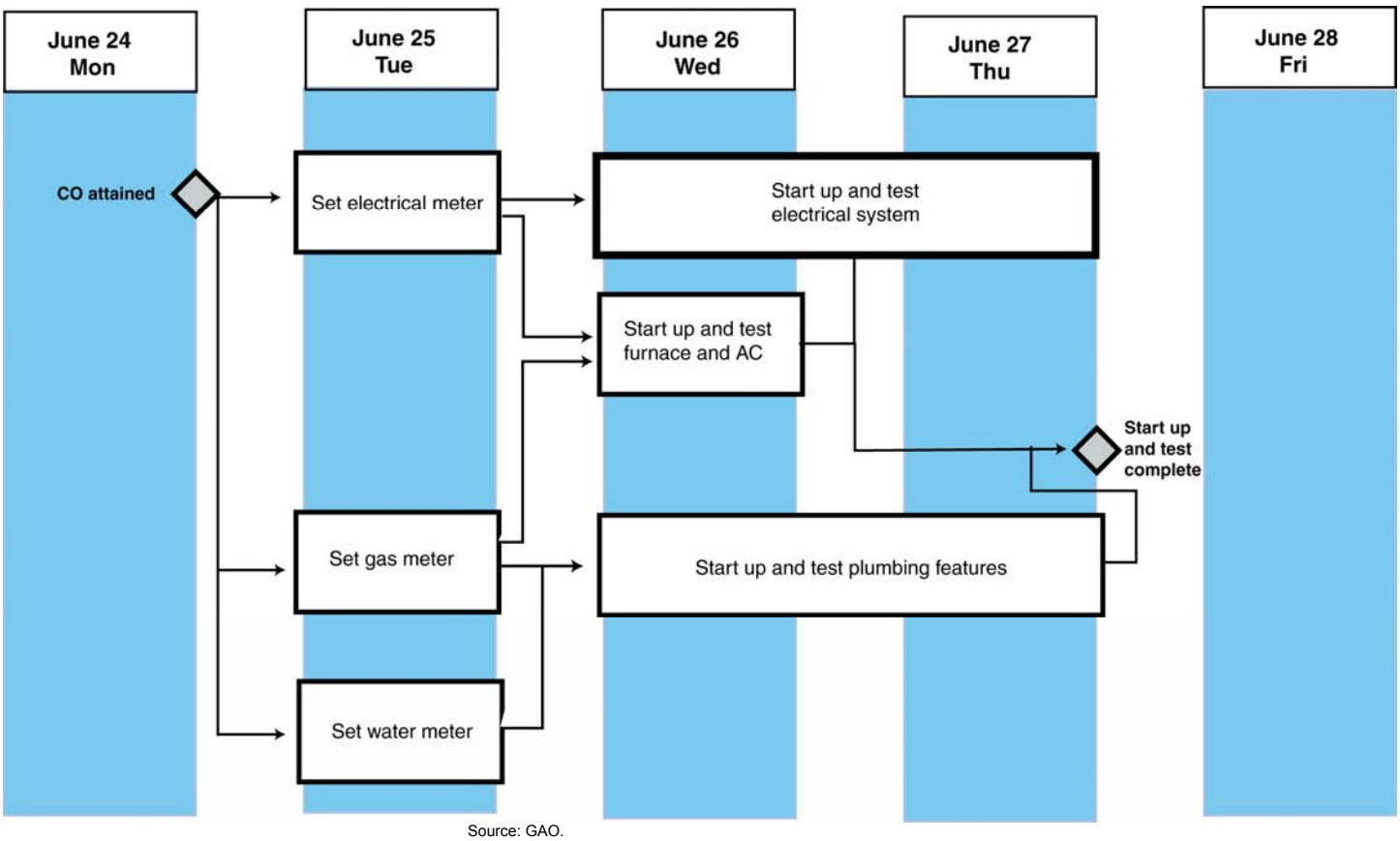
Figure 51: Start-Up and Testing Network



Source: GAO.

The activities in figure 51 are planned according to forward scheduling; that is, activities begin as soon as possible according to their predecessor and successor relationships. For example, once the electricity meter is set, start-up and testing of the electrical system can begin. Calculating the earliest dates when activities can start and finish—given their predecessor and successor logic and durations—is known as the forward pass. In the forward pass, durations are added successively through the network.

If a CO is issued at the end of the business day on Monday, June 24, then the work associated with setting the electricity, gas, and water meters can begin on Tuesday, June 25. This is the early start (ES) for these activities and is noted in a box in the upper left corner of the text box representing each activity in figure 52. To calculate the early finish (EF) of each activity, the duration is added to the ES. One day must be

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subtracted to account for the full day of work available between the early start and early finish. That is,

$$EF = ES + duration - 1.$$

The EF is noted in the upper right corner of the activity's text box. The durations are noted in between the ES and EF boxes. In these simple cases of 1-day activities, the early start and early finish dates are the same day. The numbers above the date boxes represent the cumulative duration of the project as work progresses along those dates.

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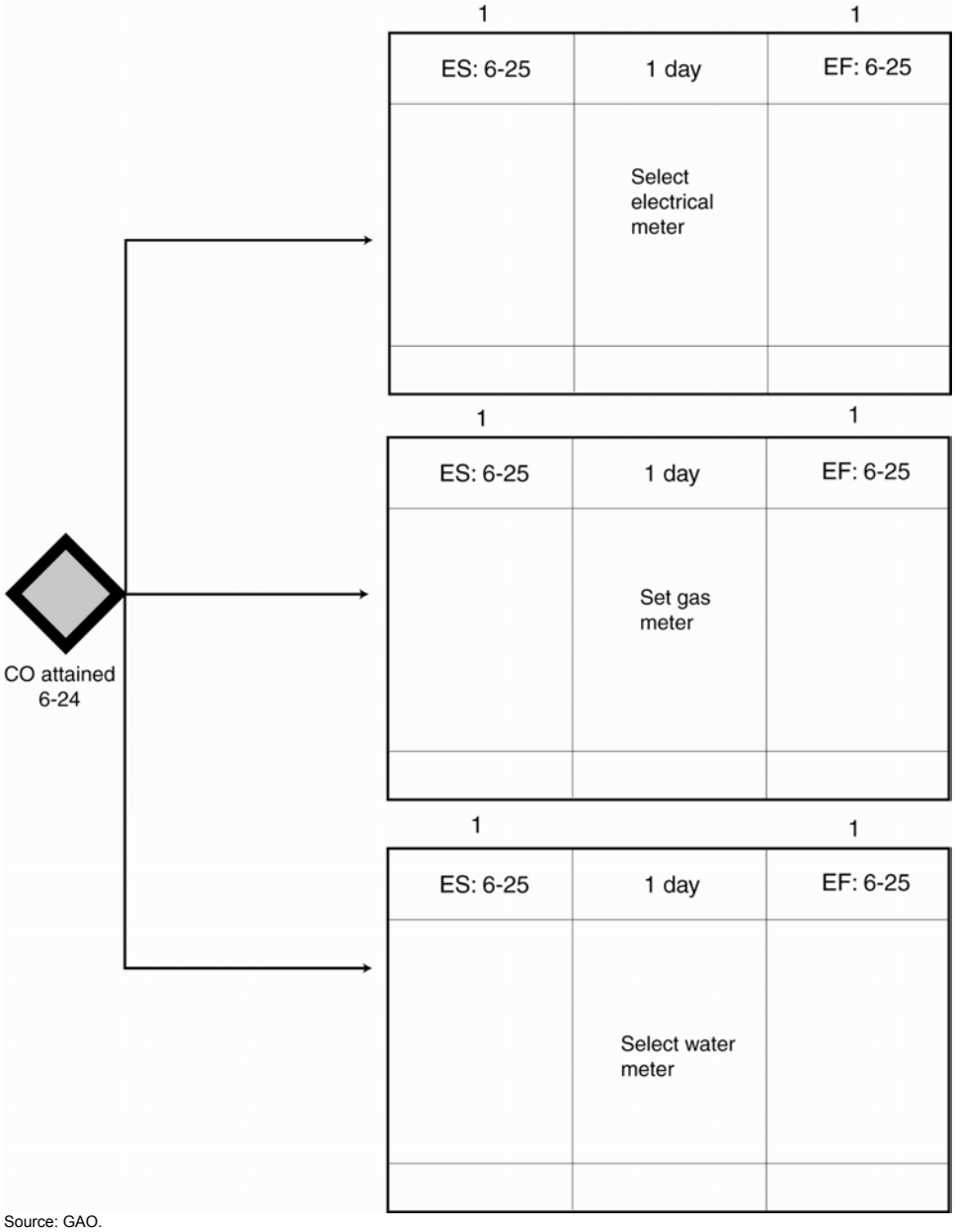
Figure 52: Early Start and Early Finish Calculations



Source: GAO.

Note: CO = Certificate of Occupancy.

Early starts of successor activities are calculated according to the logic of the network. For a single finish-to-start relationship, the early start of the

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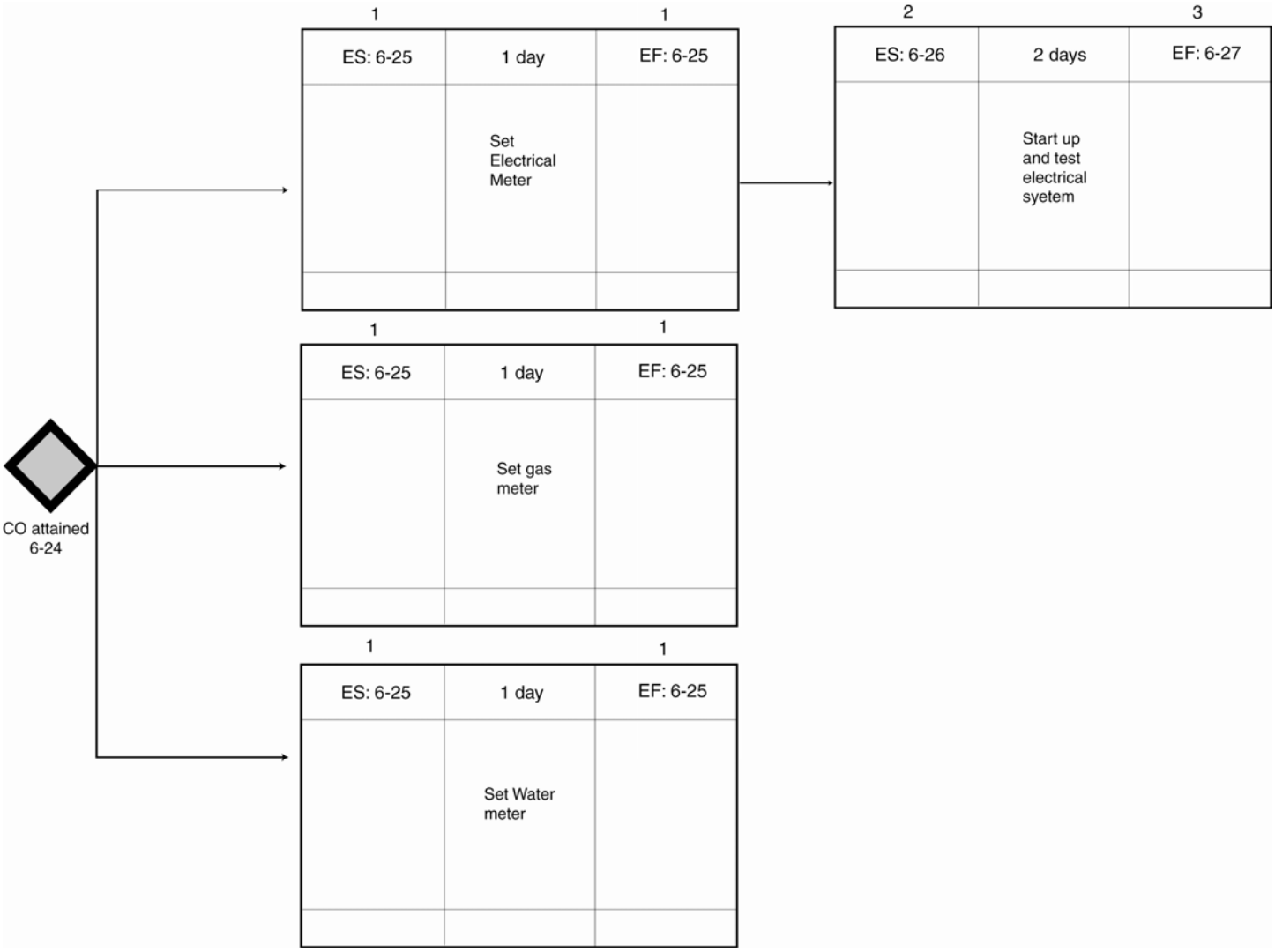
successor activity is simply the predecessor's early finish plus 1 day. The "start up and test electrical system" can begin the day after "set electricity meter" finishes, as shown in figure 53. The EF for "start up and test electrical system" is its ES (June 26) plus its 2 days of duration (June 28) and minus 1 day (June 27).

Figure 53: Successive Early Start and Early Finish Calculations



Source: GAO.

Note: CO = Certificate of Occupancy.

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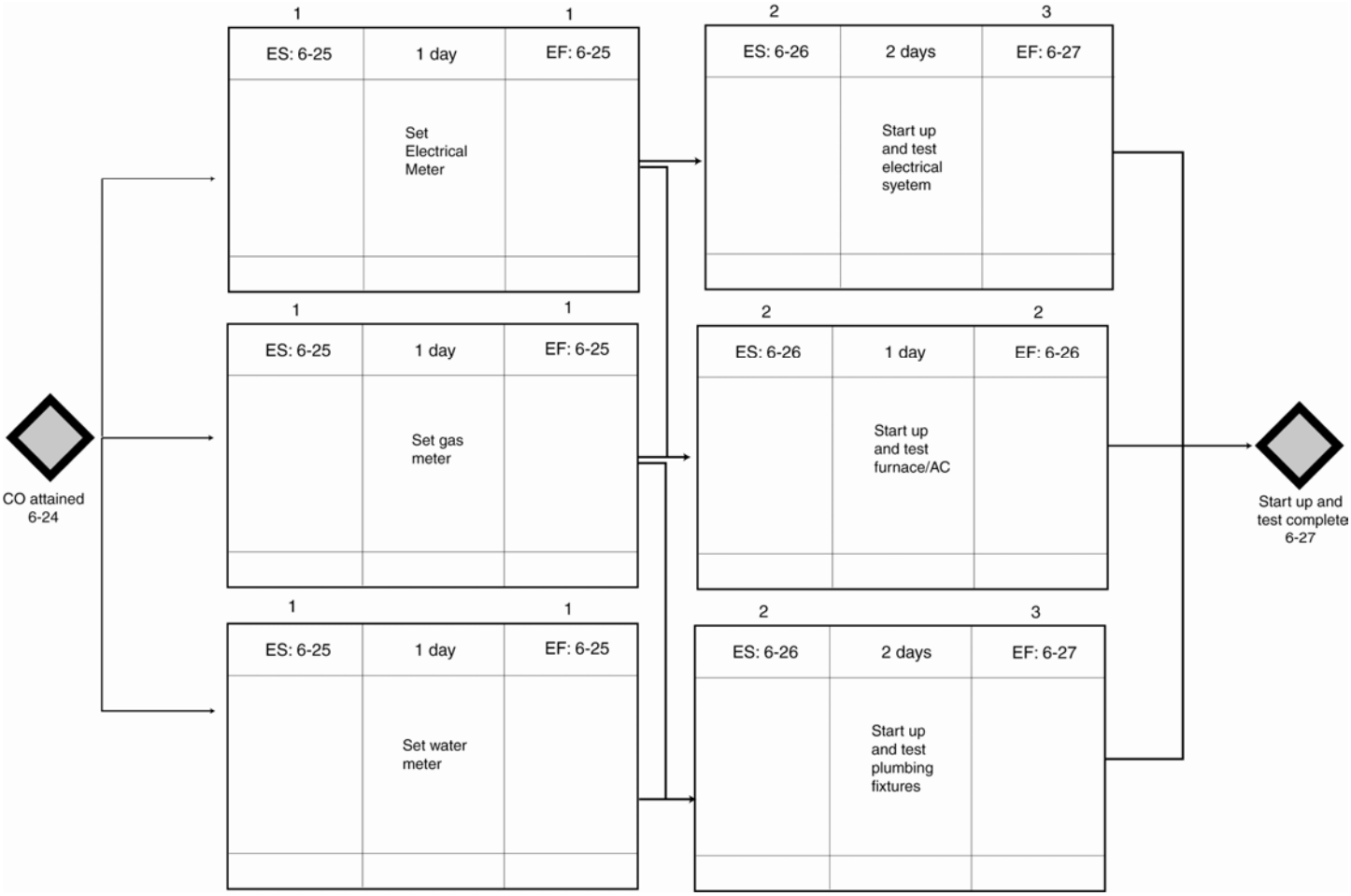
When an activity has two or more predecessor activities, the ES is calculated using the latest EF of its predecessor activities. That is, an activity cannot begin until the latest predecessor finishes. In figure 54, “start up and test furnace and AC” cannot begin until both the electricity meter and the gas meter are set. Setting the meters takes a day for each one, but they happen concurrently so they both finish on June 25. Therefore, setting the furnace and AC meters can start as early as June 26. Likewise, plumbing fixtures testing cannot begin until the gas meter and the water meter are set. But because these are both 1 day long and occur on the same day, testing plumbing fixtures can begin as early as June 26.

Figure 54: Complete Early Start and Early Finish Calculations



Source: GAO.

Note: CO = Certificate of Occupancy.

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Note that testing plumbing fixtures is expected to take 2 days as well. Its EF is calculated as its ES (June 26) plus 2 days of duration (June 28) minus 1 day (June 27). Finally, the ES of the “start up and test complete” milestone is calculated using the latest EF of its three predecessors. Both “start up and test plumbing fixtures” and “start up and test electrical system” have EF dates of June 27. Therefore, the earliest when “start up and test complete” could possibly occur is June 27 (milestones have no duration and therefore occur immediately after their latest predecessor).

As can be concluded by these calculations, the ES and EF dates are the earliest dates when an activity may start or finish. We are also interested in the latest dates when an activity must start or finish. That is, what are the latest dates when activities must start and finish in order to finish a project by a given completion date? These dates are calculated by the backward pass. Once the forward pass has been calculated, the backward pass will determine the latest possible start and finish dates for activities.

The backward pass essentially calculates how long activities can wait to start or finish and still have the project complete on time. The backward pass begins with the EF of the project. In the house construction set-up and test example, the three testing activities will each have a late finish (LF) of June 27. This is equal to the latest EF of the testing activities and, likewise, the date of the completion milestone. In figure 55 the LF is noted in the bottom right corner of each activity. To calculate an activity’s late start (LS), the duration is subtracted from its LF, and 1 day is added to account for the full day of work between the two dates:

$$LS = LF - duration + 1.$$

The LS is noted in the bottom left corner of the activity’s text box in figure 55.

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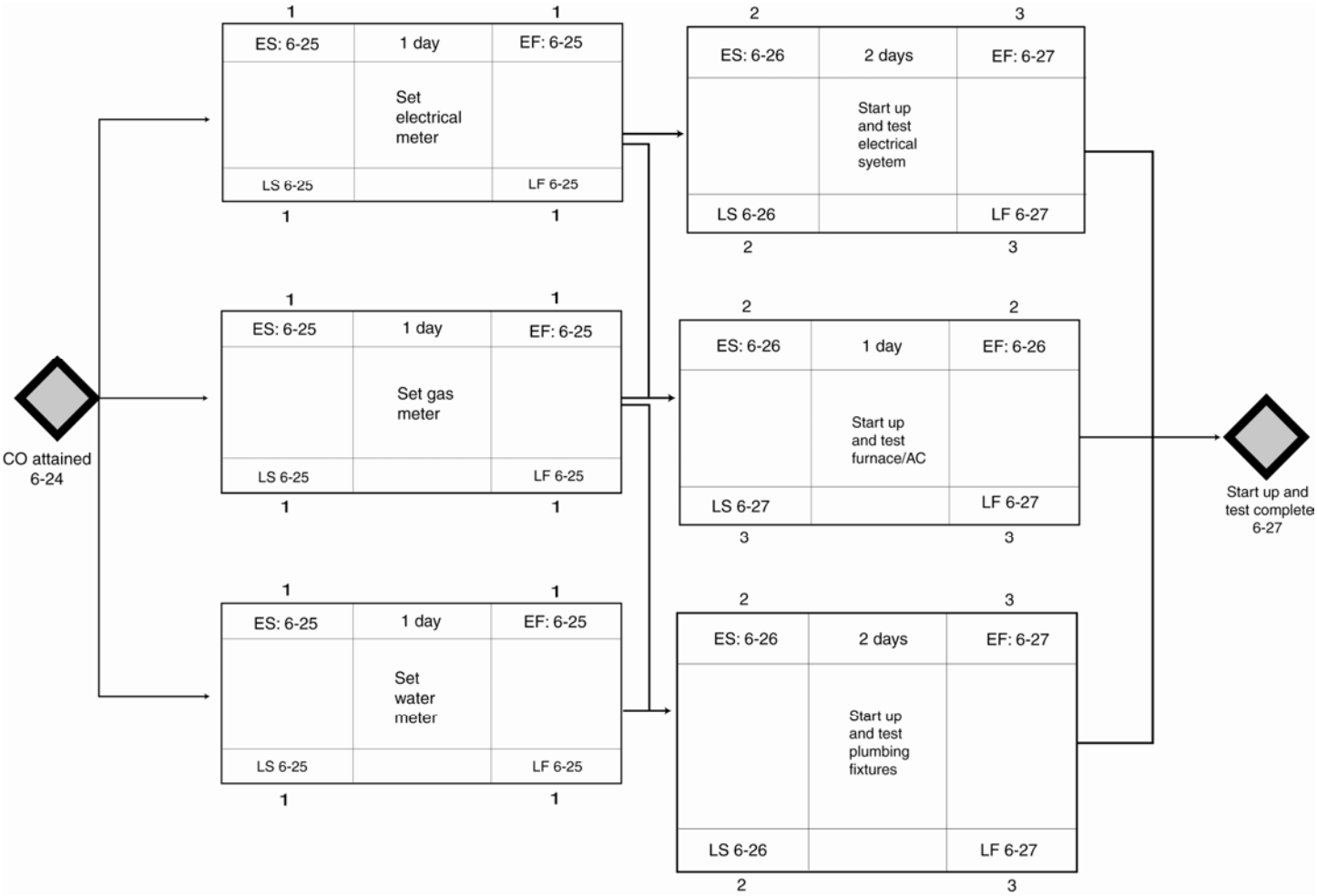
Figure 55: Late Start and Late Finish Calculations



Source: GAO.

Note: CO = Certificate of Occupancy.

When an activity has two or more successor activities, its LF is derived from the earliest LS of its successors. Stated another way, an activity does not need to finish until its successor must start; in the case of multiple successors, the earliest successor start date drives the activity's LF. In the following example, "set gas meter" has two successors: "start up and test furnace and AC" and "start up and test plumbing fixtures." The late start for testing plumbing fixtures is June 26, and the late start for

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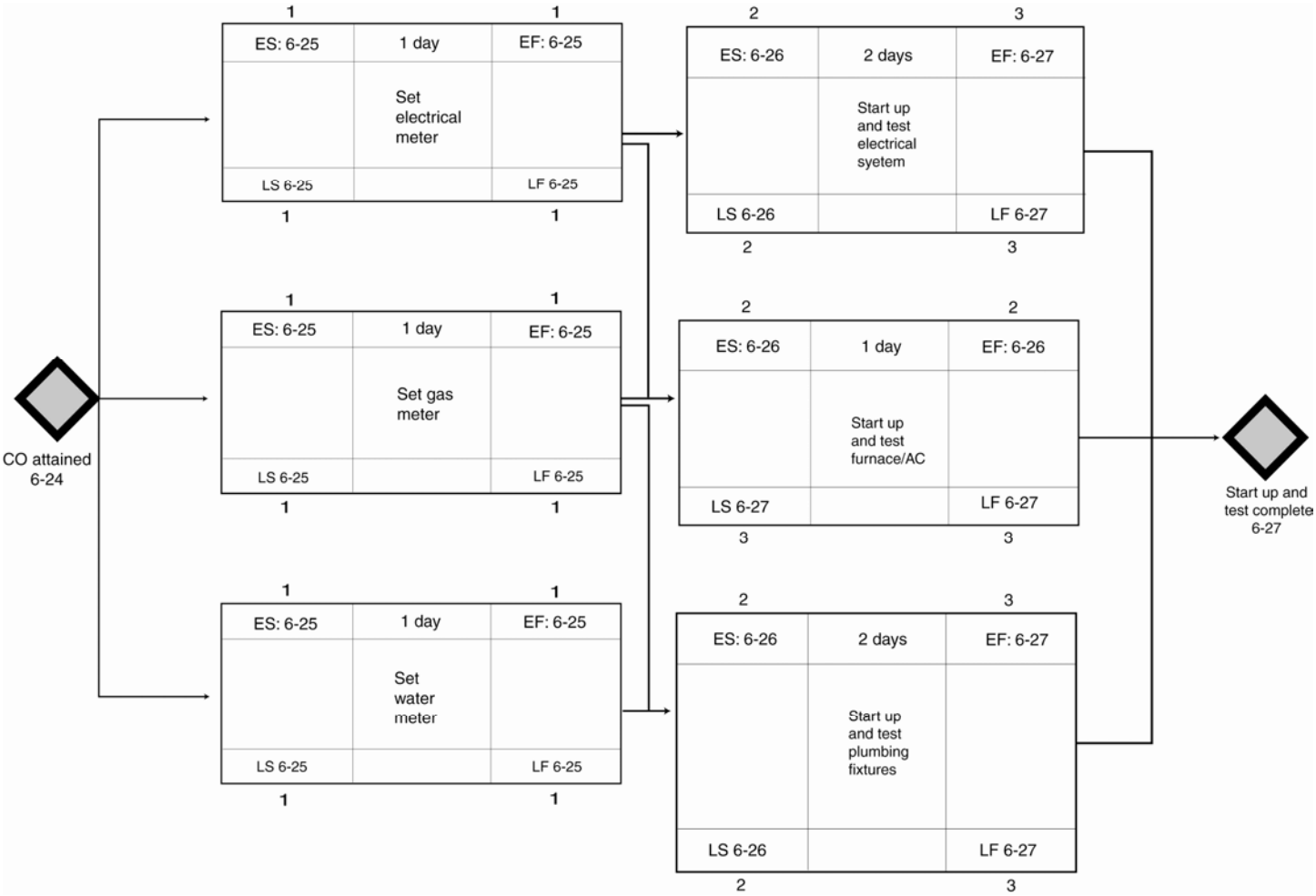
testing the furnace and AC is June 27. The LF for "set gas meter" will use the earliest LS of its successors, which in this case is June 26 for "start up and test plumbing fixtures."

The successors for "set electricity meter," test electrical system, and test furnace also have different LS dates (June 26 and 27, respectively). Its LF will therefore be June 25, 1 day before the earliest LS date. The complete forward pass and backward pass calculations are shown in figure 56.

Figure 56: Early and Late Dates of a Start-Up and Testing Network



Source: GAO.

Note: CO = Certificate of Occupancy.

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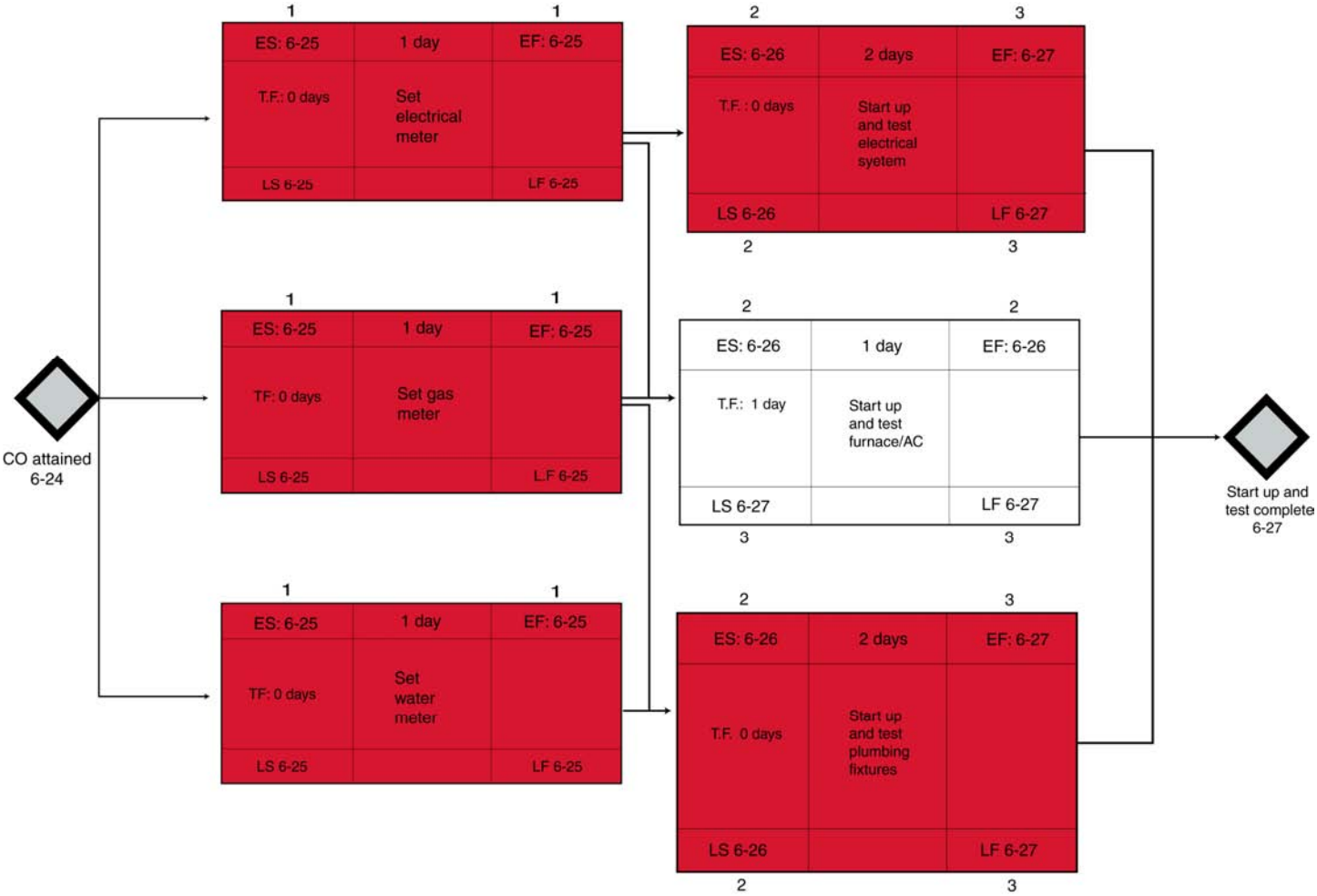
Total Float

Now that early and late dates have been derived, the schedule can be assessed for flexibility. The difference between the time an activity may start or finish (the early dates) and the time an activity must start or finish in order for the project to be completed on time (late dates) is known as total float (TF). Total float is calculated as the difference between an activity's early start and late start:

$$TF = LS - ES.$$

Total float is noted in figure 57 as "TF." Activities that have no total float are highlighted in red.

Figure 57: Total Float in a Start-Up and Testing Network



Source: GAO.

Note: CO = Certificate of Occupancy.

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All activities but one in figure 57 have zero total float. A total float value of 0 indicates that an activity has no flexibility between the date when it may start and the date when it must start or between the dates when it may finish and must finish. Any delay in its start or finish dates will transfer directly to the end milestone.

Three paths through the set-up and testing network have no total float and thus no flexibility:

1. "CO attained" → "set electricity meter" → "start up and test electrical system" → "start up and test complete";
2. "CO attained" → "set gas meter" → "start up and test plumbing fixtures" → "start up and test complete";
3. "CO attained" → "set water meter" → "start up and test plumbing fixtures" → "start up and test complete."

Any delay along the activities on these paths is transferred directly, day for day, to the finish date of the "start up and test complete" milestone, unless mitigating steps are taken.

Two paths through the set-up and testing network have total float available and thus have flexibility:

1. "CO attained" → "set electricity meter" → "start up and test furnace and AC" → "start up and test complete";

2. "CO attained" → "set gas meter" → "start up and test furnace and AC" → "start up and test complete."

Practically speaking, only one activity in the network can slip a day. None of the meter-setting activities can slip because they are all on the critical path: a slip in any one of the three will cause either the electrical system or the plumbing fixtures test to slip a day, causing the finish milestone to slip a day. Only the furnace and AC test activity can safely slip 1 day without pushing the completion milestone out. To introduce more flexibility into the schedule, the general contractor may want to assign an extra electrician to the electrical system testing. An extra resource will reduce the duration by 1 day and would therefore introduce an extra day of total float for that activity. Because total float is shared along a path, the test's predecessor, "set electricity meter," would also gain a day of total float.

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Appendix III: Standard Quantitative Measurements for Assessing Schedule Health

An assessment of schedule best practices encompasses both qualitative and quantitative information. Qualitative information is provided by programmatic questions as such as those detailed in appendix I. These questions are related to the general policies in place and procedures undertaken to create and maintain the schedule. The quantitative assessment involves a detailed data analysis of the schedule data to determine the overall health of the network. While the specific questions addressed by the data analysis are also covered in appendix I, the quantitative assessment often involves specific filters and detailed data metric definitions. These filters and definitions are in table 4 for each best practice.

Table 4: Standard Data Measures for Schedule Best Practices

Best practice	Measure	Notes
1. Capturing all activities	Measures in Best Practice 1 provide basic information on the scope of the schedule, such as number and types of activities and the level of detail	
	Total number of activities, including total summary, hammock, milestone, and detail activities	Summary activities may or may not be present in the scheduling software
	Total number of remaining activities, including total summary, hammock, milestone, and detail activities	A remaining activity is any activity that is not complete. “Remaining” may be defined as (1) an activity with an actual start or no actual start and no actual finish or (2) any activity that is not 100 percent complete. Issues may arise with either definition. For instance, an activity may be noted as 100 percent complete and not have an actual finish date, or it may have an actual start and finish date but be less than 100 percent complete. Summary activities may or may not be present in the scheduling software
	If applicable, number of activities marked as both a milestone and summary activity	An activity cannot be both a summary and a milestone
	Number of activities with no descriptive name	May or may not be valid activities
	Ratio of detail activities to milestones	Provides a rough indicator of the level of planning detail in the schedule. While there is no specific threshold, 1 or 2 detailed activities per milestone is probably a very low level of detail, while 10 is probably highly detailed
	Number of activities not mapped to program or contractor work breakdown structure	
	Number of activities not mapped to a SOW or SOO paragraph or similar information	Depending on the nature of the effort, an activity may not be mapped to the statement of work
	Number of activities with duplicate names	Activity names should be unique and descriptive

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Best practice	Measure	Notes
2. Sequencing all activities	Best Practice 2 includes more advanced measurements to assess the reliability of the network logic. Thresholds for metrics are not provided because, in theory, any missing or inappropriate logic may disrupt the entire network. The assessment of this best practice relies in part on the assessment of Best Practices 5, 6, and 7. If major deficiencies are identified in Best Practice 2, then a valid critical path, total float, and horizontal traceability are simply not possible. For minor deficiencies, an assessment of the schedule's critical path, total float, and response to tests of horizontal traceability are essential to understand the implications of constraints and incorrect or missing logic. Finally, all activities in a schedule, regardless of detail or planning period, are subject to this best practice	
	Number of remaining detail activities and milestones missing predecessor links	Does not include the start milestone; missing links to external activities (activities outside the scope of the current schedule file) may be excluded when a schedule is evaluated outside the IMS network
	Number of remaining detail activities and milestones missing successor links	Does not include the finish milestone; missing links to external activities (activities outside the scope of the current schedule file) may be excluded when a schedule is evaluated outside the IMS network
	Number of remaining detail activities and milestones missing both predecessor and successor links	
	Dangling activities: number of remaining detail activities and milestones with no predecessor on start date	Milestone activities may be excluded because their start and finish dates are the same; missing links to external activities (activities outside the scope of the current schedule file) may be excluded when a schedule is evaluated outside the IMS network
	Dangling activities: number of remaining detail activities and milestones with no successor or finish date	Milestone activities may be excluded because their start and finish dates are the same; missing links to external activities (activities outside the scope of the current schedule file) may be excluded when a schedule is evaluated outside the IMS network
	Number of remaining detail activities and milestones with start-to-finish links	Count either successor or predecessor links but do not count both. An S–F link is between two activities but represents only one link
	Number of remaining summary activities with logic links	May also be measured as "logic links to and from remaining summary activities," although this will be a different number
	Remaining detail activities and milestones with a great many predecessors	Assesses the schedule for path convergence. A relatively high number of predecessors may indicate a high-risk area. Note that not all predecessors are driving; only predecessors that have 0 or low float have the ability to delay the successor when they are delayed
	Remaining detail activities and milestones with soft date constraints	
	Remaining detail activities and milestones with hard date constraints	

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Best practice	Measure	Notes
	Remaining detail activities and milestones with active SNET date constraints	If an activity's scheduled start date is the same as the SNET date, then the SNET constraint is more than likely preventing the activity from starting early. This is considered an active constraint. If an SNET constraint is earlier than the activity's start date, then the activity is not affected by the constraint date
	Remaining detail activities and milestones with active FNET date constraints	If an activity's scheduled finish date is the same as the FNET date, then the FNET constraint is more than likely preventing the activity from finishing early. This is considered an active constraint. If an FNET constraint is earlier than the activity's finish date, then the activity is not affected by the constraint date
	Remaining detail activities and milestones with lags	Count either successor or predecessor lags but not both. A lag is between two activities but represents only one lag. This is a different number from the number of lags
	Number of lags on remaining detail activities and milestones	Count either successor or predecessor lags but not both. A lag is between two activities but represents only one lag. This is a different number from the number of activities with lags
	Remaining detail activities and milestones with leads	Count either successor or predecessor leads but not both. A lead is between two activities but represents only one lead. This is a different number from the number of leads
	Number of leads on remaining detail activities and milestones	Count either successor or predecessor leads but not both. A lead is between two activities but represents only one lead. This is a different number from the number of activities with leads
	Remaining detail activities and milestones with an F–S predecessor lead greater than remaining duration	
3. Assigning resources to all activities	Best Practice 3 is more programmatic than quantitative, although metrics and trends may be investigated for fully resource loaded schedules. If possible, resource assignments over time may be evaluated to identify potential unrealistic bow waves. In general, the measures assess the number of activities within the detail planning period that are assigned resources and the reasonableness of work hours. Overallocated resources and unrealistic resource units should be a cause for concern. Care should be taken to assess only the appropriate detailed activities	
	Total number of resources	
	Overallocated resources	
	Maximum units available per resource	Individuals should be available between 0 and 100 percent of full time, and resource groups should have a realistic number of individuals available to perform the work.
	Remaining detail activities with assignments	Exclude nonapplicable activities such as planning packages, LOE activities, and reference activities
	Remaining detail activities without assignments	
4. Establishing the durations of all activities	Measures for Best Practice 4 are generally straightforward, providing an overall assessment of the detail available to management, as well as the appropriateness of the schedule calendars. Care should be taken to assess only the appropriate detailed activities	
	Remaining detail activities with dissimilar time units	All durations should be in the same unit, preferably days

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Best practice	Measure	Notes
	Remaining detail activities with durations less than 44 days	Exclude nonapplicable activities such as planning packages and LOE and reference activities. The analyst should take into account baseline durations if available. That is, if the baseline duration is 35 days but the actual plus remaining duration is 60, the original baseline meets the intent of the best practice
	Remaining detail activities with durations greater than 44 days	
	Average duration of remaining detail activities	
	Median duration of remaining detail activities	
	Holidays and other exceptions by task calendar	
	Remaining detail activities or milestones starting or finishing on a weekend or holiday	May be legitimate but stem from incorrect calendar assignments or specifications. Milestones on weekends or holidays are particularly suspicious
5. Verifying that the schedule can be traced horizontally and vertically	Best Practice 5 has no standard measurements. Vertical traceability is assessed by determining whether lower-level tasks fall within the same timeframe as higher-level tasks and whether detailed schedule dates fall within the same timeframe as summary schedule dates. An essential check of vertical traceability is determining whether forecasted milestone dates in detailed schedules match those quoted in management briefings. Horizontal traceability depends on Best Practice 2, although not entirely as noted in that best practice. It is assessed by increasing activities' durations by improbable amounts (500 or 1,000 days) and observing how the schedule reacts. In the absence of constraints and assuming logic has been properly identified, key milestones should move and the critical path should change	
	Assessment of how critical and noncritical planned dates dynamically react to dramatic increases in predecessor activity durations	Horizontal traceability implies that the network responds dynamically to delayed activities. Severely delayed activities should become critical and previously critical paths should become noncritical. Delays of this magnitude should cause the finish date to slip relative to the activity delay
6. Confirming that the critical path is valid	Best Practice 6 has no standard measurements for assessing the critical path. Beginning at the program finish milestone, the sequence of driving activities is traced back to the status date. This sequence of activities should be straightforward, continuous, and the same as the critical path—defined by zero total float—in the absence of date constraints. Date constraints will convolute the critical path and cause activities to be critical that may not necessarily be driving the finish milestone. Critical paths to interim key milestones may also be assessed as applicable	
	Assessment of the driving paths to key milestones and comparison of those paths to activities marked as critical in the schedule	Ideally the driving path and critical path are the same to the key milestone. The path should be continuous from the status date to the key milestone and should be free of lags
7. Ensuring reasonable total float	Best Practice 7 includes basic measurements of total float to assess overall program flexibility as reported by the schedule. It is closely related to assessments of Best Practices 2, 5, and 6, because a properly sequenced network will produce reasonable estimates of float and a valid critical path. It has no thresholds or tripwire metrics; as discussed in Best Practice 7; reasonableness is assessed in combination with program length and activity type. In addition, because one logic error can cause an entire sequence of activities to report unreasonable amounts of float, the breadth of deficiencies reported in Best Practice 2 should be taken into account here. Negative float should always be questioned	
	Remaining detail activities and milestones with dissimilar total float time units	All float should be in the same units, preferably days
	Remaining detail activities and milestones with relatively high total float	High float is relative to the scope, length, and complexity of the schedule. Float should be reasonable and realistically reflect the flexibility of the schedule

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Best practice	Measure	Notes
	Remaining detail activities with negative total float	Negative total float indicates the activity's constraint date is earlier than its calculated late finish. Negative float occurs when activities are performed out of sequence
	Average total float value of remaining detail activities and milestones	
	Median total float value of remaining detail activities and milestones	
8. Conducting a schedule risk analysis	Many quantitative measurements are related to Best Practice 8, and a proper schedule risk analysis typically deserves a much more complex quantitative assessment than that given here. GAO's assessment of Best Practice 8 is more programmatic, and these questions are provided in appendix I. The metrics for Best Practice 8 are limited to determining the existence of risk data within the schedule risk file	
	Fields within the schedule used for SRA	Fields that store low, most likely, and high durations
	Correlation measures within the schedule	
	Contingency activities	
9. Updating the schedule using actual progress and logic	Best Practice 9 is assessed by determining the validity of the dates reported in the schedule. The assessment of this best practice is dependent entirely on the status date reported in the schedule	
	Number of in-progress activities	Any activity that is not complete. "Remaining" may be defined as either (1) an activity with an actual start or no actual start and no actual finish or (2) any activity that is not 100 percent complete. Issues may arise with either definition. For instance, an activity may be noted as 100 percent complete and not have an actual finish date, or it may have an actual start and finish date but be less than 100 percent complete
	Number of remaining detail activities and milestones that have a start date in the past but no actual start date	Planned start dates should not occur in the past. "Past" is defined by the status date
	Number of remaining detail activities and milestones that have a finish date in the past but no actual finish date	Planned finish dates should not occur in the past. "Past" is defined by the status date
	Number of remaining detail activities and milestones that have an actual start date in the future	Actual start dates should not occur in the future. "Future" is defined by the status date
	Number of remaining detail activities and milestones that have an actual finish date in the future	Actual finish dates should not occur in the future. "Future" is defined by the status date
	Number of detail activities performed out of sequence	
10. Maintaining a baseline schedule	Many data measures can be used to assess Best Practice 10, some are provided here. All baseline measures ultimately depend on the existence of a controlled baseline and a properly statused current schedule. Baseline measures are typically calculated by reporting period: for example, number of activities forecasted to start early over the next 60 days or activities that have actually finished late over the last 6 months. They may also be useful when applied to specific products within the WBS, resource groups, or criticality: for example, the number of late activities during product integration, the average start variance of activities executed in one production plant, or the baseline execution index of activities with less than 10 days of total float	

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Best practice	Measure	Notes
	Number of remaining detail activities and milestones that are forecasted to start or finish before their baseline dates	Represents activities and milestones forecasted to begin or end early
	Number of remaining detail activities and milestones that are forecasted to start or finish on their baseline dates	Represents activities and milestones forecasted to begin or end on time
	Number of remaining detail activities and milestones that are forecasted to start or finish after their baseline dates	Represents activities and milestones forecasted to begin or end late
	Number of remaining detail activities that actually started before their baseline start date	Represents activities and milestones that actually started early
	Number of remaining detail activities that actually started on their baseline start date	Represents activities and milestones that actually started on time
	Number of remaining detail activities that actually started after their baseline start date	Represents activities and milestones that actually started late
	Number of remaining detail activities and milestones that actually finished before their baseline finish date	Represents activities and milestones that actually finished early
	Number of remaining detail activities and milestones that actually finished on their baseline finish date	Represents activities and milestones that actually finished on time
	Number of remaining detail activities and milestones that actually finished after their baseline finish date	Represents activities and milestones that have actually finished late
	Average and median start variance	Start variance may be the difference between actual start and baseline start or forecasted start and baseline start
	Average and median finish variance	Finish variance may be the difference between actual finish and baseline finish or forecasted finish and baseline finish
	Baseline execution index	The ratio of actual completed detail activities to detail activities that were planned to finish. A BEI of 1 indicates that the project is performing according to plan. A BEI less than 1 indicates that, in general, fewer activities are being completed than planned; a BEI greater than 1 indicates that, in general, more activities are being completed than planned

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Appendix IV: Recommended Elements of a Data Collection Instrument

- The baseline IMS and the latest updated IMS, including all applicable embedded project schedules. Their format should be that of a software schedule file such as Microsoft Project or Primavera P6. PDF and PowerPoint files are not valid schedule file formats and are not acceptable. Note the software used to create and maintain the schedule.
- A schedule dictionary or similar documentation that defines custom fields, especially those that contain information on level of effort activities; contractor versus government effort; and statement of work, statement of objective, work package, integrated master plan, or control account mappings.
- Integrated master pan (IMP), if applicable.
- Work breakdown structure (WBS) and dictionary.
- A statement of work (SOW) or statement of objectives (SOO) and mission requirements.
- A cross-walk between the WBS or SOW and the schedule activities.
- An identification of the main deliverables, including a designation of the paths that the project considers critical.
- The schedule baseline and narrative documentation.
- A basis of estimate or other documentation for estimating activity durations and assigned resources.
- Relevant scheduling guidance, such as contract line item numbers, data item descriptions, and agency directives that govern the creation, maintenance, structure, and status of the schedule.
- Schedule risk analysis documentation, including the analytical approach, assumptions, and results.
- A risk management plan and a copy of the current risk watch list.

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Appendix V: Case Study Backgrounds

We drew the material in the guide's 19 case studies from the 11 GAO reports described in this appendix. Table 5 shows the relationship between reports, case studies, and the chapters in which they are cited. The table is arranged by the order in which we issued the reports, earliest first. Following the table, paragraphs describe the reports and are ordered by the numbers of the case studies in the guide.

Table 5: Case Studies Drawn from GAO Reports Illustrating this Guide

Case study	GAO report	Best practices cited
2	GAO-09-518: Military Readiness	1
19	GAO-10-59: 2010 Census	10
7, 14	GAO-10-43: Transportation Worker Identification Credential	4, 8
3, 16	GAO-10-189: VA Construction	1, 8
6	GAO-10-378: Nuclear Nonproliferation	3
13	GAO-10-816: Nuclear Waste	7
1, 4, 5, 17	GAO-11-53: DOD Business Transformation	1, 2, 9
8, 18	GAO-11-740: Aviation Security	5, 9
15	GAO-11-743: Coast Guard	8
9, 11	GAO-12-66: Immigration Benefits	5, 6
10, 12	GAO-12-223: FAA Acquisitions	6, 7

Case Studies 1, 4, 5, and 17: From *DOD Business Transformation*, GAO-11-53, October 7, 2010

The Department of Defense (DOD) invests billions of dollars annually to modernize its business systems. Consequently, the DOD business systems modernization program has been on our high-risk list since 1995. In its modernization, DOD is implementing nine enterprise resource planning (ERP) efforts that perform business-related tasks such as general ledger accounting and supply chain management. These efforts are essential to transforming DOD's business operations.

We were asked to determine whether selected ERPs followed schedule and cost best practices. We found that none of the four programs we assessed had developed a fully integrated master schedule as an effective management tool. Such a tool is crucial to estimating the overall schedule and cost of a program. Without it, DOD is unable to say, with any degree of confidence, whether the estimated completion dates are realistic.

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Case Study 2: From *Military Readiness*, GAO-09-518, September 25, 2009

DOD reports data about the operational readiness of its forces. In 1999, the Congress directed DOD to create a comprehensive readiness system with timely, objective, and accurate data. In response, DOD started to develop the Defense Readiness Reporting System (DRRS). After 7 years, DOD had incrementally fielded some capabilities and reported obligating, through fiscal year 2008, about $96.5 million. We were asked to review the program, including the extent to which DOD had (1) effectively managed and overseen DRRS acquisition and deployment and (2) implemented features of the DRRS consistent with legislative requirements and DOD guidance.

First, we compared DRRS acquisition disciplines with DOD's related guidance and, second, we reviewed the DRRS's current and intended capabilities relative to legislative requirements and DOD's guidance. We found that DOD had not effectively managed and overseen DRRS acquisition and deployment. In large part, this ineffectiveness was caused by the absence of rigorous and disciplined acquisition management controls and an effective governance and accountability structure. Moreover, the DRRS had not been guided by a reliable schedule of work to be performed and key activities to take place. Such management weaknesses can, in part, be attributed to long-standing limitations in office staffing and system oversight and accountability.

Case Studies 3 and 16: From *VA Construction*, GAO-10-189, December 14, 2009

The Department of Veterans Affairs (VA) operates one of the largest health care systems in the country. As of August 2009, VA's Veterans Health Administration (VHA) had 32 major ongoing construction projects, with an estimated total cost of about $6.1 billion and average cost per project of about $191 million. Some of these projects were initiated as part of VA's Capital Asset Realignment for Enhanced Services (CARES) process, which was a comprehensive assessment of VHA's capital asset requirements. In response to a congressional request, we (1) described how costs and schedules of current VHA major construction projects had changed, (2) determined the reasons for changes in costs and schedules, and (3) described the actions VA had taken to address cost increases and schedule delays.

We reviewed construction documents, visited three construction sites, and interviewed VA and general contractor officials. We found that while about half of the 32 major ongoing construction projects were within their budget, since they were first submitted to the Congress, 18 had been subject to cost increases, 11 to schedule delays, and 5 to a cost increase of over 100 percent. For example, the cost of a new medical center in Las

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Vegas rose from an initial estimate of $286 million to over $600 million, an increase of about 110 percent. In addition, 13 projects had been subjected to cost increases of between 1 and 100 percent and 11 to schedule delays, 4 of which were longer than 24 months. There were several reasons for project cost increases and schedule delays, including VA's preparing initial cost estimates that were not thorough; significant changes to project scope after the initial estimate was submitted; and unforeseen events, such as an increase in the cost of construction materials.

Case Study 6: From *Nuclear Proliferation*, GAO-10-378, March 26, 2010

The end of the Cold War left the United States with a surplus of weapons-grade plutonium that posed proliferation and safety risks. Much of this material was to be found in a key nuclear weapon component known as a pit. The Department of Energy (DOE) planned to dispose of at least 34 metric tons of plutonium by fabricating it into mixed oxide (MOX) fuel for domestic nuclear reactors. To do so, DOE's National Nuclear Security Administration (NNSA) was constructing two facilities—a MOX Fuel Fabrication Facility (MFFF) and a Waste Solidification Building (WSB)—at the Savannah River Site in South Carolina. We were asked to assess the (1) cost and schedule status of the MFFF and WSB construction projects, (2) status of NNSA's plans for pit disassembly and conversion, (3) status of NNSA's plans to obtain customers for MOX fuel from the MFFF, and (4) actions that the Nuclear Regulatory Commission (NRC) and DOE had taken to provide independent nuclear safety oversight.

To develop our analysis, we reviewed NNSA documents and project data, toured DOE facilities, and interviewed officials from DOE, NRC, and nuclear utilities. We found that the MFFF project was subject to schedule delays stemming, in part, from the delivery of reinforcing bars that did not meet nuclear quality standards.

Case Studies 7 and 14: From *Transportation Worker Identification Credential*, GAO-10-43, December 10, 2009

The Transportation Worker Identification Credential (TWIC) program, managed by the Department of Homeland Security's (DHS) Transportation Security Administration (TSA) and the U.S. Coast Guard, required maritime workers who accessed secure areas of transportation facilities to obtain a biometric identification card to gain access. A TWIC regulation set a national compliance deadline of April 15, 2009. In part to inform the development of a second TWIC regulation, TSA was conducting a pilot program to test the use of TWICs with biometric card readers. We were asked to evaluate (1) TSA's and the Coast Guard's progress and related challenges in implementing TWIC and (2) the

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management challenges, if any, that TSA, the Coast Guard, and DHS faced in executing the TWIC pilot test.

We reviewed TWIC enrollment and implementation documents and conducted site visits or interviewed officials at the seven pilot program sites. We found that TSA had made progress in incorporating management best practices to execute the TWIC pilot test, aimed at informing the Congress. But TSA faced two management challenges to ensure the successful execution of the test and the development of the second TWIC regulation. First, TSA faced problems in using the TWIC pilot schedule to both guide the pilot and accurately identify the pilot's completion date. Although TSA had improved its scheduling practices in executing the pilot, weaknesses remained, such as not capturing all pilot activities in the schedule. This could adversely affect the schedule's usefulness as both a management tool and a means of communication among pilot participants.

Second, shortfalls in planning for the TWIC pilot hindered TSA and the Coast Guard's efforts to ensure that the pilot (1) represented deployment conditions and (2) would yield the information needed—such as the operational effects of deploying biometric card readers and their costs—to accurately inform the Congress and develop the second regulation. This was partly because TSA and the Coast Guard had not developed an evaluation plan that fully identified the scope of the pilot or specified how information from the pilot would be analyzed. The current evaluation plan described data collection methods but did not identify the evaluation criteria and methodology for analyzing the pilot data once they were collected. A well-developed, sound evaluation plan would help TSA and the Coast Guard determine how the data were to be analyzed to measure the pilot's performance.

Case Studies 8 and 18: From *Aviation Security*, GAO-11-740, July 12, 2011

Explosives represent a continuing threat to aviation security. To detect explosives, TSA used the Electronic Baggage Screening Program (EBSP) for checked baggage. To identify and resolve threats in checked baggage, the program includes the use of the explosives detection system (EDS) in conjunction with explosives trace detection (ETD) machines.

We analyzed EDS requirements, compared the EDS acquisition schedule against our best practices, and interviewed DHS officials. We found that TSA had faced challenges in procuring the first 260 EDSs to meet 2010 requirements. For example, the danger associated with some explosives

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challenged TSA and DHS in developing simulants and collecting data on the explosives' physical and chemical properties. Vendors and agencies needed these data to develop detection software and test EDSs before acquisition. In addition, TSA's decision to pursue EDS procurement during data collection complicated both efforts and resulted in a delay of over 7 months for the 2011 EDS procurement.

TSA could have helped avoid additional schedule delays by completing data collection for each phase of the 2010 requirements before pursuing EDS procurement that met those requirements. Although TSA had established a schedule for the 2011 EDS procurement, (1) the schedule did not fully comply with our best practices and (2) TSA had not developed a plan to upgrade its EDS fleet to meet the 2010 requirements.

Case Studies 9 and 11: From *Immigration Benefits*, GAO-12-66, November 22, 2011

Each year, using a paper-based process, DHS's U.S. Citizenship and Immigration Services (USCIS) handles millions of applications for immigration benefits. In 2005, USCIS embarked on a major multiyear program meant to transform its current process to a system that would incorporate electronic application filing, adjudication, and case management. In 2007, we reported that USCIS planned, in the early stages of the program, to partially or fully meet best practices. In 2008, USCIS contracted with a solutions architect to help develop the new program.

We reviewed DHS's acquisition management policies and guidance; analyzed transformation program planning and implementation documents, such as operational requirements; compared schedule and cost information with our guidance for best practices; and interviewed USCIS officials. We found that USCIS was continuing to manage the program without specific acquisition management controls, such as reliable schedules, that would have detailed work to be performed by both the government and its contractor over the expected life of the program. As a result, USCIS did not have reasonable assurance that it could meet its future milestones. In particular, although USCIS had established schedules for the first release of the transformation program, our analysis showed that these schedules were unreliable because they did not meet best practices for schedule estimating.

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Case Studies 10 and 12: From *FAA Acquisitions*, GAO-12-223, February 16, 2012

The Federal Aviation Administration (FAA), partnering with other federal agencies and the aviation industry, is implementing the Next Generation Air Transportation System (NextGen), a new satellite-based air traffic management system that will replace the current radar-based system and is expected to enhance the safety and capacity of the air transport system by 2025. In a review of 30 major ATC acquisition programs, all contributing to the transition to NextGen, GAO found that costs for 11 of the 30 programs had increased from their initial estimates by a total of $4.2 billion and that 15 programs had experienced delays. The 11 acquisitions accounted for over 60 percent of FAA's total acquisition costs ($11 billion of $17.7 billion) for the 30 programs. The 15 acquisitions, 10 of which also had cost increases, ranged from 2 months to more than 14 years and averaged 48 months.

To determine the extent to which selected ATC programs adhered to best practices for determining acquisition costs and schedules, we conducted an in-depth review of 4 of the 30 acquisitions programs: the Automatic Dependent Surveillance-Broadcast (ADS-B) system, the Collaborative Air Traffic Management Technologies (CATMT) system, the System Wide Information Management (SWIM) system, and the Wide Area Augmentation System (WAAS). In addition to interviews, we collected documentation, and we analyzed and summarized the views and information we collected. We also performed a schedule risk analysis of the WAAS program to determine the likelihood of the project's finishing on schedule.

FAA was not consistently following the characteristics of high-quality cost estimates and scheduling best practices for the four programs GAO analyzed. Regarding scheduling practices, most programs did not substantially or fully meet the majority of the 9 best practices GAO previously identified, including developing a fully integrated master schedule of all program activities and performing a schedule risk analysis. For example, without a schedule risk analysis, FAA is unable to predict, with any degree of confidence, whether the estimated completion dates are realistic.

FAA is implementing new processes and organizational changes to better manage acquisitions. However, by not consistently following the characteristics of high-quality cost estimate and scheduling best practices, FAA cannot provide reasonable assurance to the Congress and other stakeholders that NextGen and other ATC programs will avoid additional cost increases or schedule delays.

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Case Study 13: From *Nuclear Waste*, GAO-10-816, September 14, 2010

At DOE's Savannah River Site in South Carolina, decades of nuclear materials production had left 37 million gallons of radioactive liquid waste in 49 underground storage tanks. In December 2008, DOE entered into a contract with Savannah River Remediation, LLC (SRR), to close, by 2017, 22 of the highest-risk tanks at a cost of $3.2 billion.

We visited the Savannah River Site and reviewed tank closure documents. We also analyzed the construction schedule of the Salt Waste Processing Facility (SWPF). This facility was vital to successful tank closure because the SWPF was to treat a large portion of the waste removed from the tanks. We found that the SWPF construction schedule did not fully meet the best scheduling practices we identified. For example, the schedule had problems with excess float between activities, indicating that these activities may not have been sequenced logically. To mitigate the effects of construction delays, DOE was exploring ways to deploy new technologies to treat radioactive waste. However, additional research and development on these new technologies was required. Therefore, it would be several years before they could be deployed.

Case Study 15: From *Coast Guard*, GAO-11-743, July 28, 2011

The Deepwater Program—the largest acquisition program in the Coast Guard's history—began in 1996 as an effort to recapitalize the Coast Guard's operational fleet, including ships, aircraft, and other supporting capabilities. In 2007, the Coast Guard took over the lead systems integrator role from the Integrated Coast Guard Systems, establishing a $24.2 billion overall program baseline.

We reviewed key Coast Guard documents and applied criteria from the GAO *Cost Guide*. We found that the estimated total acquisition cost of the Deepwater Program, based on approved program baselines as of May 2011, could have been as much as approximately $29.3 billion, or about $5 billion more than the $24.2 billion baseline approved by DHS in 2007. However, we also found that two factors precluded a solid understanding of the program's true cost and schedule: (1) the Coast Guard had not yet developed revised baselines for all assets, including the Offshore Patrol Cutter—the largest cost driver in the program—and (2) the Coast Guard's most recent capital investment plan indicated further cost and schedule changes not yet reflected in the asset baselines. We also found that the reliability of the cost estimates and schedules for selected assets were undermined because the Coast Guard did not follow key best practices for developing these estimates.

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Case Study 19: From *2010 Census*, GAO-10-59, November 13, 2009

To carry out the decennial census, the U.S. Census Bureau conducts a sequence of thousands of activities and numerous operations. As requested, we examined its use of (1) scheduling tools to maintain and monitor progress and (2) two control systems key to field data collection—one to manage the work flow for paper-based operations, including nonresponse follow-up, and the other to manage quality control for two major field operations. We applied schedule analysis tools; reviewed the Bureau's evaluations, planning documents, and other documents on work flow management; and interviewed Bureau officials.

We found that as the Bureau carries out the census, its master schedule provides a useful tool to gauge progress, identify and address potential problems, and promote accountability. We also found that the Bureau's use of its master schedule generally follows leading scheduling practices, which allow such high-level oversight. However, the errors we found in the Bureau's master schedule were hindering its ability to identify the effects of activity delays and to plan for the unexpected.

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Appendix VI: Experts Who Helped Develop This Guide

The two lists in this appendix name the experts in the scheduling community, along with their organizations, who helped us develop this guide. This first list names significant contributors to the *Schedule Guide*. They attended and participated in numerous expert meetings, provided text or graphics, and submitted comments.

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This second list names those who generously donated their time to review this guide in its various stages and who provided feedback.

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